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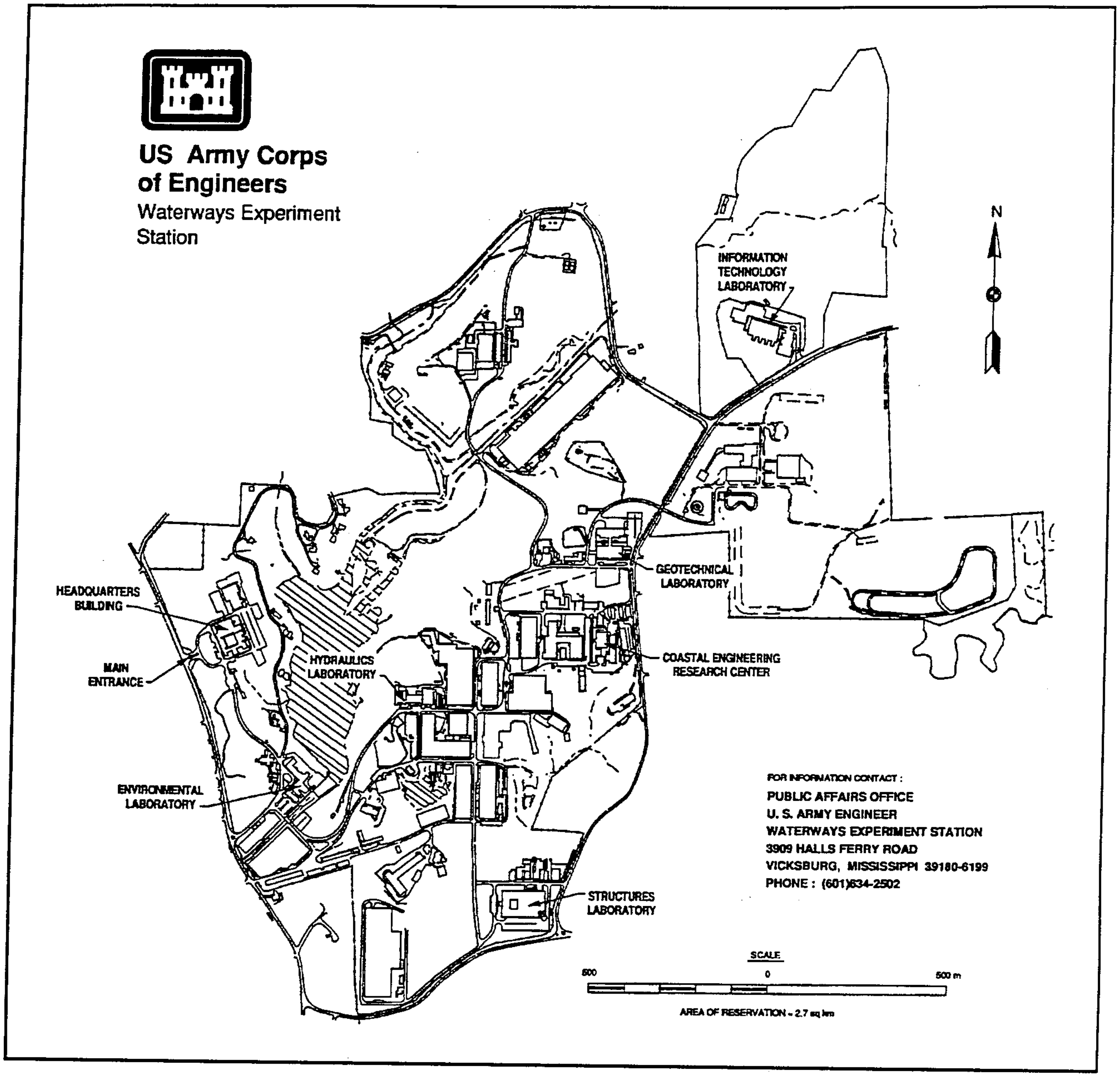
Assessment of Native Beach Characteristics for St. Joseph, Michigan-Southeastern Lake Michigan

by Larry E. Parson, J. Bailey Smith

Prepared for Headquarters, U.S. Army Corps of Engineers



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Assessment of Native Beach Characteristics for St. Joseph, Michigan-Southeastern Lake Michigan

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Final report

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Preface

The investigation summarized in this report was conducted by the U.S. Army Engineer Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC) and was selected for study and funded by the Monitoring Completed Coastal Projects (MCCP) Program. The MCCP Program Manager is Ms. Carolyn Holmes, CERC. This program is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). The HQUSACE Technical Monitors are Messrs. John H. Lockhart, Jr.; Charles Chesnutt; and Barry W. Holliday. The project is under the jurisdiction of the U.S. Army Engineer District, Detroit (NCE).

Work was performed under the general supervision of Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch (CSEB), CERC; Mr. Thomas W. Richardson, Chief, Engineering Development Division, CERC; Mr. Charles C. Calhoun, Jr., Assistant Director, CERC; and Dr. James R. Houston, Director, CERC.

This report was prepared by Mr. Larry E. Parson and Mr. J. Bailey Smith, CSEB, CERC. Field data collection was performed by many individuals of NCE, Grand Haven Area Office, and CERC. Technical assistance in preparing manuscripts, figures, and general support coordination was provided by Mr. Danny Marshall and Ms. Sherry Andrews, CSEB, CERC. Technical reviewers of the report were Dr. Andrew Morang, CSEB, CERC, Mr. Ronald Erickson, U.S. Army Engineer District, Detroit, and Mr. Charles Thompson, U.S. Army Engineer District, Detroit.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard.

1 Introduction

Purpose

Beach nourishment has become a common engineering solution for beach erosion control and restoration in the Great Lakes and has been recognized as beneficially affecting the stability of downdrift shorelines. A monitoring program to evaluate the behavior of coarse-grained nourishment material in southeastern Lake Michigan is in progress at St. Joseph, Michigan. Work is being conducted by the U.S. Army Engineer Waterways Experiment Station's Coastal Engineering Research Center (CERC) under the Monitoring Completed Coastal Projects Program. The monitoring program has been divided into four main activities: (a) determining *native beach* and fill sediment characteristics; (b) investigating *geologic controls* on nearshore morphology; (c) evaluating improved *retention of coarse fill material*; and (d) determining *downdrift benefits* from the use of coarse fill. A prerequisite component of achieving these objectives is determining native beach characteristics of the project area, which is the topic of this report. The other monitoring activities listed above shall be addressed in subsequent reports.

Accurately evaluating and classifying native beach characteristics is essential to understanding the response of coastal areas to structures and erosion mitigation projects. Techniques commonly used for U.S. Army Corps of Engineers coastal projects were employed in determining the native characteristics of the St. Joseph project area. However, these widely used techniques are developed primarily for sandy beaches and may not accurately represent the highly variable and irregular range of sediment gradation (clay to coarse gravel) that exists at St. Joseph and throughout many areas of the Great Lakes. The objective of this investigation is to evaluate the use of widely accepted sandy beach sediment sampling techniques in determining native characteristics in areas of the Great Lakes such as St. Joseph.

Background

St. Joseph is located on the southeastern shore of Lake Michigan approximately 32 km (20 miles) north of the Indiana/Michigan border (Figure 1). In 1903, parallel jetties were constructed to stabilize the entrance of the St. Joseph River (Figure 2). These jetties have been proven to be responsible for downdrift shoreline erosion. The U.S. Army Engineer District, Detroit (1973) determined that the jetties interrupt the southward transport of approximately 84,101 m^3 (110,000 yd^3) of sediment per year. In 1976, an approved Section 111 erosion mitigation plan authorized annual placement of fill material from maintenance dredging of the St. Joseph Harbor to feed the eroding downdrift shoreline. To date, 1.5 million m^3 (2 million yd^3) of dredged material have been deposited on

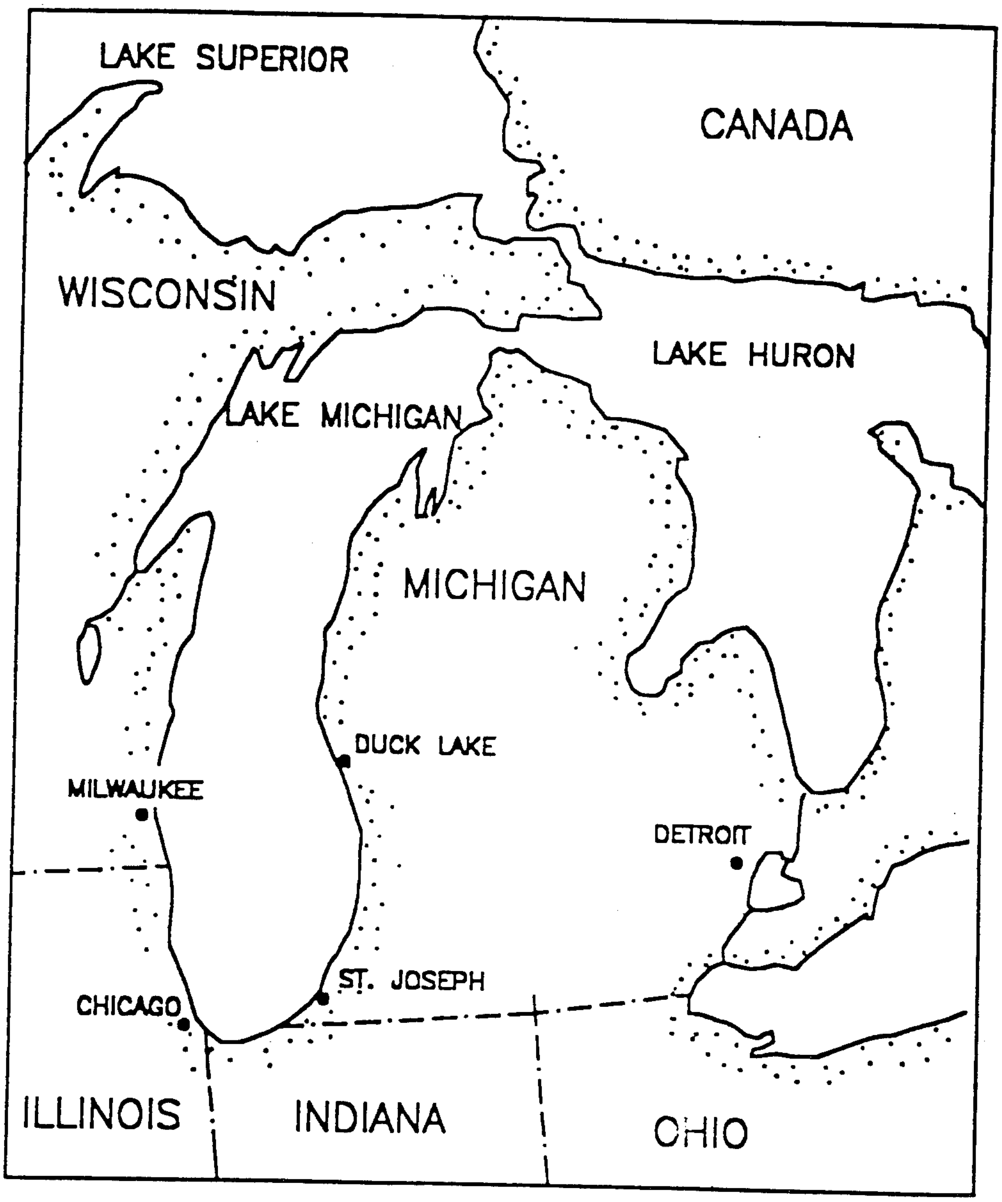

Figure 1. Location of St. Joseph, Michigan, project area

the beaches south of the jetties as summarized in Table 1. The most recent coarse fill (1991) was placed south of the jetties and was intended to act as a feeder beach to replenish the downdrift shore. This fill was hauled by truck from a commercial upland site and was deposited on the feeder beach.

Table 1
Summary of Beach Fills at the St. Joseph Project Area

Year	Dredged, m^3 (yd^3)	Trucked, m^3 (yd^3)	Type
1970	22,900 (30,000)		Fine
1971	16,300 (21,300)		Fine
1972	32,900 (43,000)		Fine
1973	61,000 (8,000)		Fine
1974	6,100 (25,600)		Fine
1975	38,800 (50,800)		Fine
1976[1]	72,000 (94,200)	212,600 (278,000)	Fine
1977	123,900 (162,000)		Fine
1978	68,400 (89,500)		Fine
1979	84,700 (110,800)		Fine
1980	71,100 (93,000)		Fine
1981	50,300 (65,800)		Fine
1982	89,900 (117,600)		Fine
1983	169,400 (221,500)		Fine
1984	76,500 (100,000)		Fine
1985	28,800 (37,700)		Fine
1986	11,200 (14,700)	120,400 (157,500)	Fine/coarse
1987	2,500 (3,300)	47,800 (62,500)	Fine/coarse
1988		84,600 (110,700)	Coarse
1989	14,300 (18,700)		Fine
1990	38,200 (50,000)		Fine
1991	40,100 (52,500)	(71,100)	Fine/coarse
1992	27,500 (36,000)		Fine
Total	1,146,800 (1,420,400)	465,400 (679,700)	1,612,200 (2,100,100)

[1]Denotes implementation of Section 111 Plan.

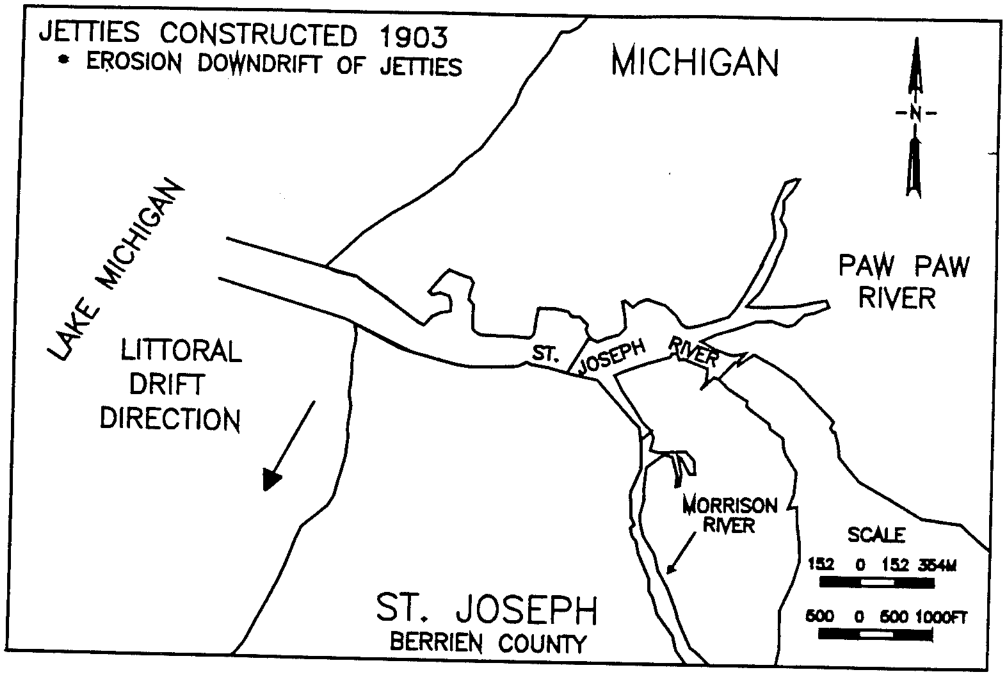

Figure 2. Parallel jetties stabilizing the entrance of St. Joseph Harbor

Physical Setting

The shoreline within the project area is a product of the last ice age from the Pleistocene Period 18,000 years ago. Following the maximum southerly advance of the ice sheets, glacial recession created, exposed, and modified glacial deposits, accompanied by drastic changes in lake levels. These events were responsible for shaping the present shoreline features (Raphael and Kureth 1988). Benton and Passero (1990) classified four types of glacial deposits in the St. Joseph vicinity: moraines, outwash plains, lacustrine, and eolian. Moraines form along glacial margins outlining the position of maximum ice advancement. Morainal sediments are typically complex mixtures of gravel, sand, and clay, a material called *glacial till.* Outwash plains are deposits composed primarily of sand and gravel originating from glacial meltwater. Lacustrine deposits, mostly clay, are deposited in lakes where meltwaters that carry fine sediment accumulate. Eolian processes are responsible for coastal sand dunes.

The shoreline of St. Joseph consists of unconsolidated bluffs and dune fields overlying consolidated sediments which extend for several kilometers (Hands 1970). These shorelines are particularly susceptible to the erosive forces of the dominant storm waves approaching from the northwest, especially during periods of higher lake levels. Much of the existing sand on the beaches and in offshore bars is derived from the erosion of the existing bluffs and dunes. This erosion produces beaches and nearshore zones consisting of a relatively thin layer of sand with scattered lag deposits of gravel which overlie the regional cohesive glacial till. Thus, a highly variable sediment gradation ranging from clay to coarse gravel exists within these zones. These areas are also characterized by highly irregular sediment zonations as opposed to the more uniform zonations of sandy beaches described by Stauble et al. (1993).

Historically, the nearshore region is characterized by gentle nearshore slopes (approximately 1:80) and the presence of multiple longshore bars. Although Saylor and Hands (1970) observed the bars to slowly migrate in response to varying lake level conditions, the bars were considered to be relatively stable features of the profile. Some areas of the local nearshore were described by Meisberger, Williams, and Prins (1979) as areas of clay underlying a thin veneer of sand and gravel less than 0.46 m (1.5 ft) thick. Sauck identified locations on the lakebed within the project area where glacial till has become exposed.[1]

Private land owners have constructed numerous and varied structures to stabilize the damaged shoreline immediately south of the project area. In many cases, severe erosion of downdrift properties adjacent to the structures as well as flanking of the protective structures has resulted (U.S. Army Engineer District (USAED), Detroit 1973). Scour and erosion of the lakebed have occurred adjacent to many of these structures. Preliminary studies by Foster et al. (1992) documented downcutting of the nearshore lakebed in excess of 3.7 m (12 ft) south of the Federal structures near the village of Shoreham. Structures range from seawalls, revetments, bulkheads, groins, and breakwaters made from various materials to heaps of construction rubble and old automobiles pushed over the face of the bluffs. Beaches are small or nonexistent in these sediment-starved areas. Where pocket beaches do occur, the sediment is composed of coarse sand and gravel.

Hubertz, Driver, and Reinhard (1991) utilized wave hindcasting techniques to describe the historic wave environment for the St. Joseph area. The predominant direction of wave approach is from the southwest, which normally occurs during periods of low wave energy with mean wave height of 0.8 m (2.6 ft) and a mean wave period of 4.0 sec. The maximum wave height from this direction is 4.6 m (15.1 ft). The predominant wave energy approaches from the north and northwest, where the mean wave height is 1.2 m (3.9 ft) with a mean wave period of 4.8 sec. The maximum wave height from these directions, 6.3 m (20.6 ft), generally occurs during the stormy winter months. The longer fetch distances to the north and northwest across the lake allow larger waves to develop than those that form over the shorter fetches from the south and southwest (USAED, Detroit 1973). This wave climate causes a predominant alongshore littoral drift from north to south as indicated by the accumulation of material and updrift offset to the north of the harbor jetties. Periodic reversals occur during the low energy periods, as evident by the lesser accumulation of material against the south jetty (Figure 2).

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[1] Personal Communication, 1993, W. Sauck, Department of Geophysics, Western Michigan University, Kalamazoo, MI.

Project History and Description

Nourishment at the feeder beach site was authorized under Section 111 of the River and Harbor Act of 1968. The project involves placing fill material to provide feeder beaches to mitigate shore damage resulting from the entrapment or diversion of littoral transported sediments by the St. Joseph Harbor navigation structures (USAED, Detroit 1977). The feeder beach at Lions Park starts at the centerline of Park Street, 381 m (1,250 ft) south of the St. Joseph jetties, and extends southward 854 m (2,800 ft) to 1,235 m (4,050 ft) south of the jetties (Figure 3). The coarse renourishment prompting this study occurred during September, 1991, when 54,500 m^3 (71,000 yds^3) of coarse material was placed along the feeder beach. The material was brought by truck from an upland commercial site and placed between the ordinary high water mark (el 177.1 m (580.8 ft)) and the most landward 1.2-m (4-ft) depth contour (el 174.6 m (572.8 ft)) to provide a maximum width of 46 m (150 ft). The maximum design height for the placed material was an elevation of 178.3 m (584.8 ft). The material was uniformly distributed within the restricted limits of design.

The 1991 borrow material was a glacial outwash (moraine) sand-gravel composite free of clay, organic soil, sod, roots, brush, wood, rubbish, oil, metal, chemical contaminants, and other waste materials. The material exhibits a poorly sorted, bimodal distribution of gravel and sand with a mean composite grain size of -1.21 ϕ (2.31 mm) and a standard deviation of 2.69, as illustrated in Figure 4.

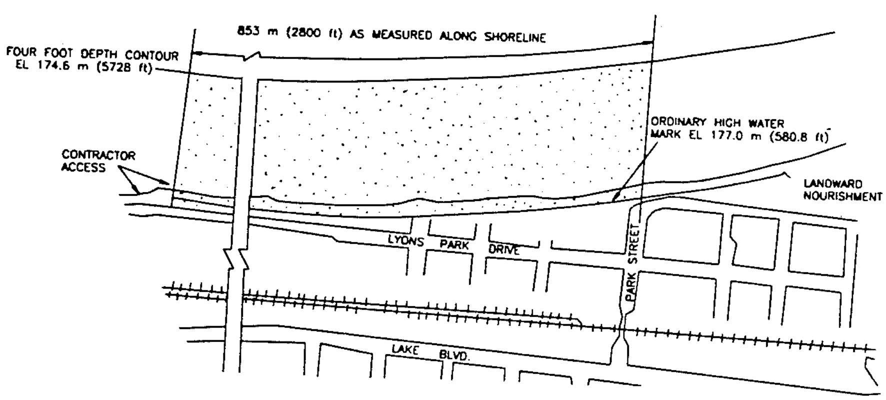

Figure 3. Project fill construction features

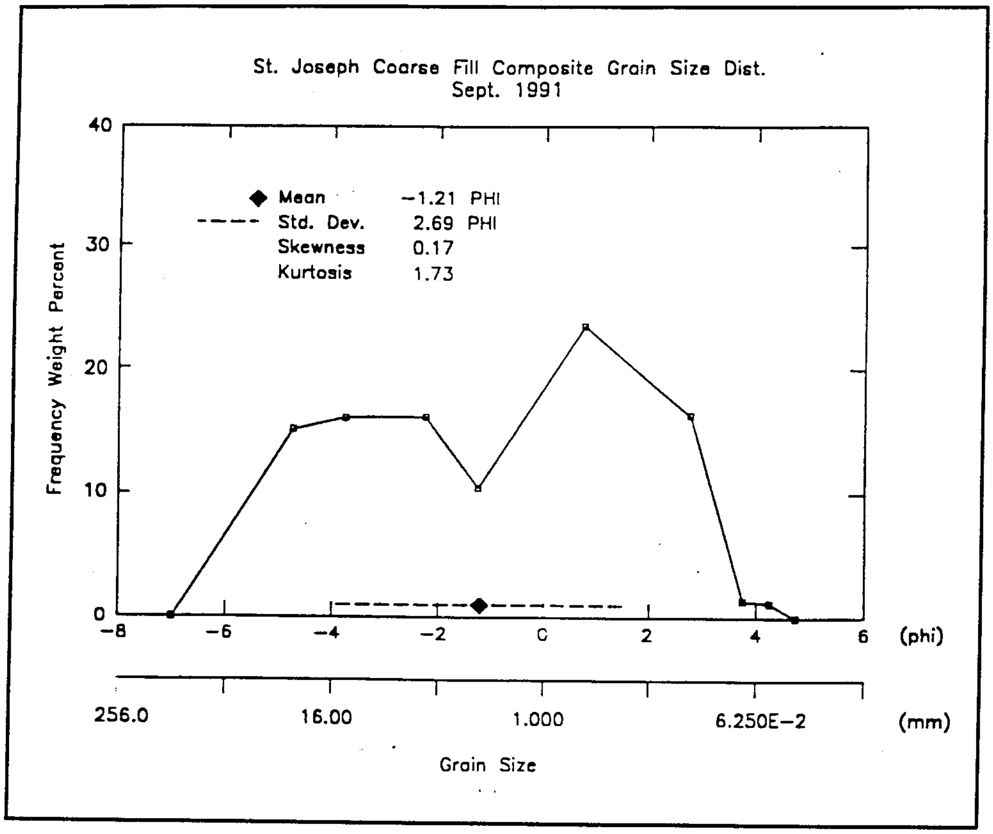

Figure 4. Composite grain size distribution of the coarse fill material

Monitoring Program

Stauble (1988; 1991a) presents comprehensive monitoring procedures for beach nourishment projects. Although developed for sandy shorelines, these procedures provide the foundation for monitoring the behavior of the St. Joseph beach nourishment. Five data collection sites or profile lines (R-9, R-9a, R-10, R10a, and R-11) spaced approximately 152 m (500 ft) apart (Figure 5) were selected to characterize the behavior of the immediate fill area. Profile lines R-8 and R-12, immediately north and south of the project area, serve as control lines. Additional profiles south of the fill area were selected to assess the downdrift benefits of the fill. These lines, R-14, R-17, R-20, R-22, and R-23, are spaced roughly 0.8 km (0.5 miles) apart. All profiles extend from a stable location on the beach not affected by coastal processes (behind dune, seawall, or bluff line) on a line normal to the shoreline, extending lakeward as far as possible to capture the assumed active profile.

Onshore and offshore sediment samples were collected during each profile survey to characterize the active envelope of fill response. Sediment redistribution across the entire profile was monitored during each survey by collecting surface sediment samples at various morphological locations across the profile consistent with accepted beach sediment sampling

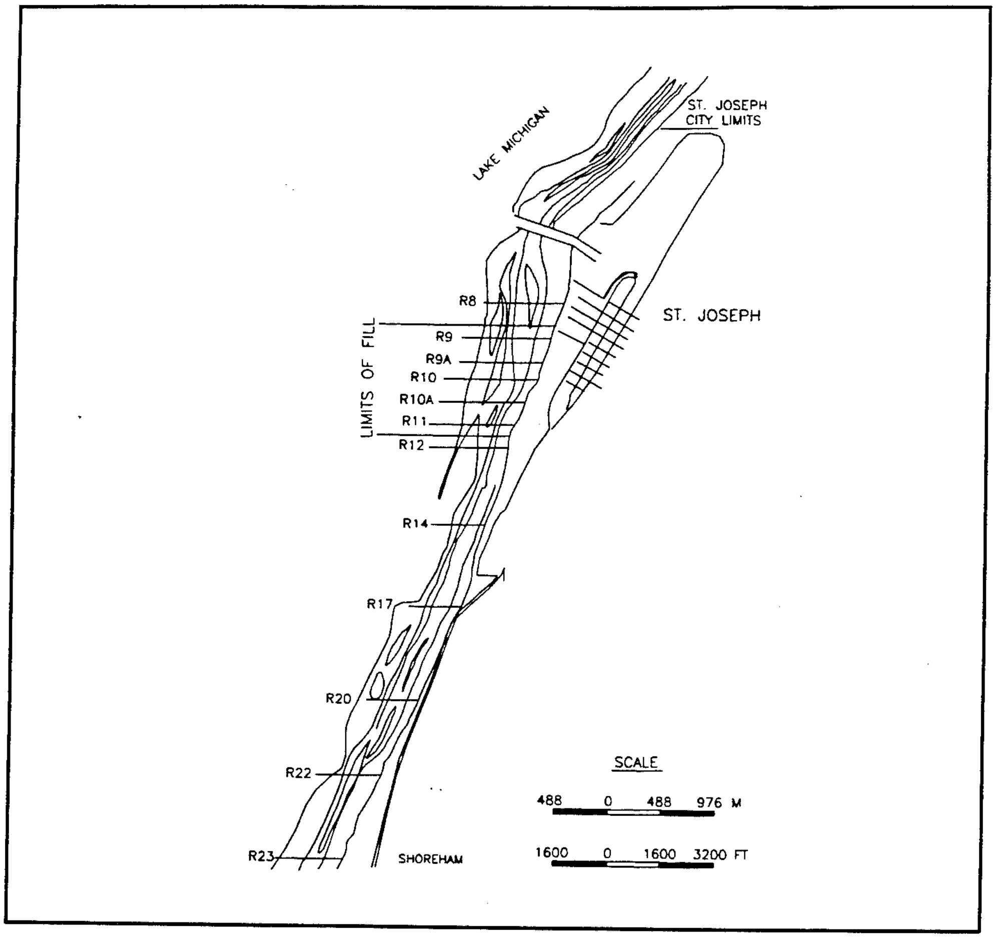

Figure 5. Location of St. Joseph project data collection sites

techniques described by Stauble (1992), Byrnes (1989), Stauble (1988), and the *Shore Protection Manual* (SPM) (1984). These sampling locations were: toe of dune/bluff; mid-berm; shoreline; bar trough; bar crest; bar seaward slope; and depth of closure as illustrated in Figure 6. If a bar system was absent or not previously known, samples were taken at 0.9-m (3-ft) contour intervals to a depth of 6.4 m (21 ft). The data collection schedule was the same for both the profile surveys and the sediment collection. Survey data and sediment samples were collected just prior to and as soon as possible after fill placement.

A three-dimensional sediment sampling scheme was employed at the fill site as well as at downdrift and updrift locations. The primary purpose of this procedure was to determine the depth of the underlying clay surface. Comparisons of the data will be performed to determine if fine fill derived from the placement of dredged material has resulted in accelerated erosion of the cohesive sediment surface causing permanent damage to the nearshore profiles (a process described by Kamphuis (1987) and Nairn (1992)).

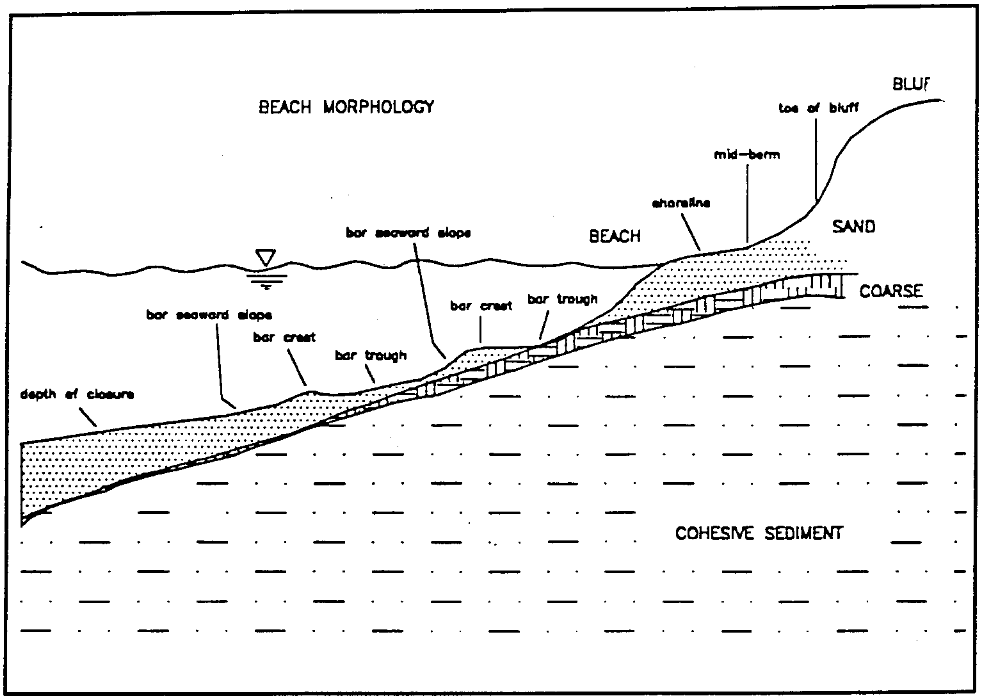

Figure 6. Location of sediment samples along the profile for the St. Joseph monitoring project

Three-dimensional data imaging was performed with ground penetrating radar (GPR), a technique that shows potential as being a valuable tool to examine the shallow stratigraphy of the beach and nearshore in freshwater environments. GPR relies upon the emission, transmission, reflection, and reception of electromagnetic energy and is capable of producing continuous, high-resolution profiles of the subsurface that are similar to those produced by seismic profiling methods. It is believed that the data obtained from GPR will verify the occurrence of clay (cohesive sediment) within the actively moving (eroding) substratum, documenting the exposure of the cohesive underlayer to the potential abrasion by wave energy. Documenting this process will establish the importance of providing and maintaining an adequate protective sand cover over the cohesive underlayer. GPR surveys were run normal to shore coinciding with each profile survey line and concentrate mostly on the profile sites south of the feeder beach. Shore-parallel GPR lines intersecting the shore-normal lines were also run near the shore and towards the outer reaches of the profile survey lines.

Wave information is an essential part of the evaluation of any coastal erosion mitigation project. Ideally, a nearshore directional wave gauge is desirable to monitor wave transformation and provide data on longshore currents for assessing longshore movement of beach material. However, because a wave gauge was unavailable, wave hindcasting techniques were employed to generate the necessary wave information.

Aerial photography overflights of the project area are being performed at least bi-yearly. The photographs provide a cost-effective method to assess the behavior of the entire project and adjacent shoreline areas. The color photographs at a scale of 1:6000 will be used to construct a base map and document shoreline change throughout the life of the project.

2 Pre-fill Beach Characteristics

Native beach characteristics south of St. Joseph have been obscured given the fill history of the area. For more than 20 years prior to this study, maintenance dredging of St. Joseph Harbor accounted for annual placement of fine-grained material (2.25 ϕ or 0.2 mm) on the beaches south of St. Joseph, totalling nearly 1.1 million m^3 (1.5 million yd^3). Sediment sizes are expressed in phi (ϕ) units as devised by Krumbein (1934, 1938) and are cross-referenced to millimeters for convenience. The continual placement of this fine sediment has contaminated or biased the native characteristics (Parson 1992). In addition, 252,300 m^3 (330,000 yd^3) of coarse-grained material was placed south of the harbor prior to the 1991 project, further masking the beach's native characteristics. Sediment samples used to represent the pre-fill beach were collected in the feeder beach area and at the control sites to the north and south (profile lines R-8, R-9, R-9A, R-10, R-10A, R-11, and R-12). The sediment samples were collected using a Peterson surficial grab sampler during April 1991 immediately prior to the placement of maintenance dredging material. The samples collected at this time are the only data available that represent the modern pre-fill characteristics of the feeder beach area.

It should be noted that the April 1991 sampling represents the winter conditions for the St. Joseph area. Knowledge of winter beach conditions can be particularly useful because the coarser grains, which are more stable during winter or storm are usually present on the beach surface as lag deposits (Anders and Hansen 1990). The winter beach characteristics are of greatest concern in the Great Lakes, for it is the more stable coarser beach material that forms the last line of defense against the winter wave attack after finer-grained sediment has been eroded and removed from the beach.

Sediment Analysis

Sediment samples collected at the project site were analyzed at CERC's sediment laboratory. Grain size analyses of the samples were performed using a dry sieving technique outlined by Folk (1980). The methodology employed the sonic sifter described by Underwood (1988) which uses sound waves to enhance the shaking motion of the sediment particles, allowing for faster sieving times and smaller initial samples. Statistical analysis of each sediment sample, performed on CERC's Automated Coastal Engineering System (ACES) software used the method of moments, a computational method in which each grain size class is considered in the results. This method, used for determining all sediment statistics cited throughout this report, is considered to be a more accurate measure than graphical methods (Leenknecht, Szuwalski, and Sherlock 1990). All samples were mathematically combined to determine the composite sediment characteristics for the entire feeder beach area. A summary of the various composite sediment analyses is presented in Appendix A. Sediment size classifications are described according to the Wentworth size classification (Wentworth 1922) and presented in Table 2.

Results of the composite beach sediment characteristics are presented in Figure 7. As discussed earlier, native beach sediment characteristics at St. Joseph have been obscured by the continuous placement of material from other sources since 1970. Typical grain size variation across the active profile as described by Hobson (1977) is not evident. The pre-fill composite mean grain size for the feeder beach area is 1.63 ϕ (0.32 mm), with a standard deviation of 1.27, indicating a moderately to poorly sorted distribution. A skewness value of -1.14 indicates a distribution skewed toward the coarser end of the distribution or an excess of coarse material. Composite grain size analyses containing each sample location (Appendix A) across the profile, summarized in Table 3, show that the coarsest material occurs at the shoreline, as expected, with a poorly sorted mean grain size of -0.10 ϕ (0.93 mm). The mean composite grain size of samples taken from the mid-berm is 1.54 ϕ (0.34 mm). The composite mean increases landward to 0.31 ϕ (0.81 mm) at the toe of the bluff. The grain size increase at the toe of the bluff is artificial, remnant of previous coarse fills in the back-beach areas (Parson 1992). Samples lakeward of the shoreline become better sorted and progressively decrease in mean grain size to about 2.00 ϕ (0.25 mm) at the -2.7-m (-9-ft) contour, remaining relatively constant thereafter out to the -4.6-m (-15-ft) contour. Mean grain size increases to 1.62 ϕ (0.33 mm) at the -5.5-m (-18-ft) contour and then sharply decreases to 2.30 ϕ (0.20 mm) at the -6.4-m (-21-ft) contour. The variation in sediment gradation across the profile necessitates including all samples when determining the pre-fill composite grain size characteristics.

Table 2
Sediment Particle Sizes in Relation to the Wentworth Scale

Unified Soils Classification	ASTM Mesh No.	MM size	PHI Size	Wentworth Classification	
		4096.00	-12.0		
		1024.00	-10.0	Boulder	
Cobble		256.00	-8.0		
		128.00	-7.0		
		107.64	-6.75	Cobble	
		90.51	-6.5		
		76.00	-6.25		
		64.00	-6.0		
		58.82	-5.75		
Coarse Gravel		45.26	-5.5		
		38.00	-5.25		
		32.00	-5.0		
		26.91	-4.75		
		22.63	-4.5		Gravel
		19.00	-4.25	Pebble	
		16.00	-4.0		
		13.45	-3.75		
Fine Gravel		11.31	-3.5		
		9.51	-3.25		
	2.5	8.00	-3.0		
	3	6.73	-2.75		
	3.5	5.66	-2.5		
	4	4.76	-2.25		
Coarse Sand	5	4.00	-2.0		
	6	3.36	-1.75	Granule	
	7	2.85	-1.5		
	8	2.35	-1.25		
	10	2.00	-1.0		
	12	1.68	-0.75	Very Coarse	
Medium Sand	14	1.41	-0.5		
	16	1.19	-0.25		
	18	1.00	0.0	Coarse	
	20	0.84	0.25		
	25	0.71	0.5		
	30	0.59	0.75		
	35	0.50	1.0	Medium	
	40	0.42	1.25		
	45	0.35	1.5		
	50	0.30	1.75		Sand
Fine Sand	60	0.25	2.0	Fine	
	70	0.210	2.25		
	80	0.177	2.5		
	100	0.149	2.75		
	120	0.125	3.0	Very Fine	
	140	0.105	3.25		
	170	0.088	3.5		
	200	0.074	3.75		
Silt	230	0.0625	4.0	Silt	
	270	0.053	4.25		
	325	0.044	4.5		
	400	0.037	4.75		
		0.031	5.0		
		0.0156	6.0	Clay	
		0.0078	7.0		
		0.0039	8.0		
Clay		0.0020	9.0		
		0.00098	10.0		Mud
		0.00049	11.0		
		0.00024	12.0	Colloid	
		0.00012	13.0		
		0.00006	14.0		

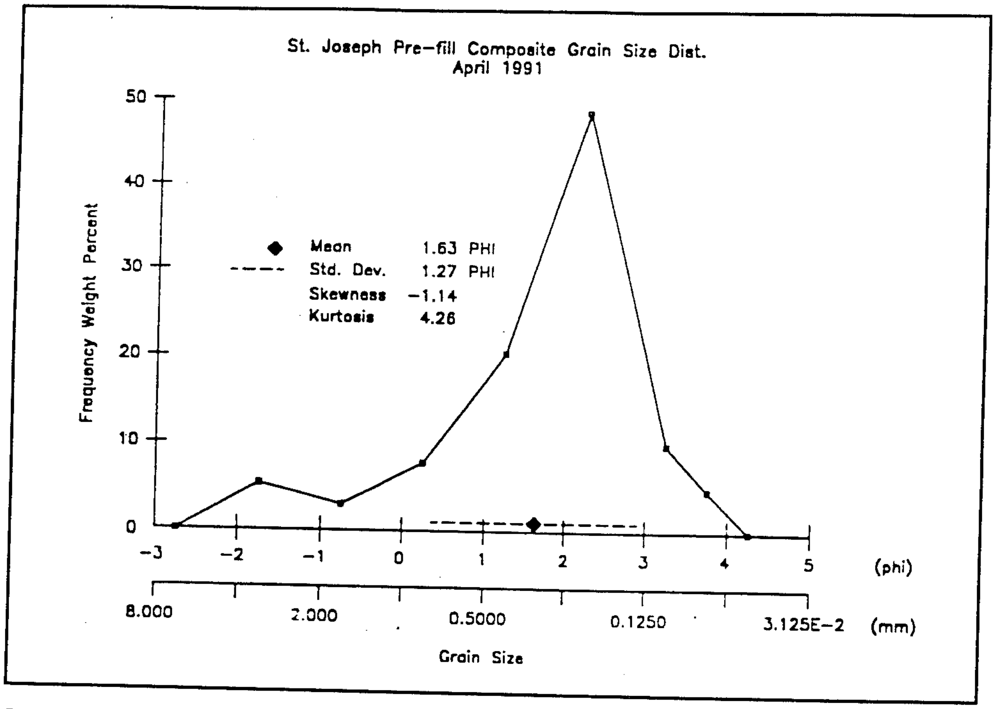

Figure 7. Pre-fill composite grain size distribution for the St. Joseph feeder beach area

Table 3
Summary of the Composite Sediment Characteristics from April 1991 Across the Profile for the Feeder Beach Area

	Mean (ϕ/mm)	Sorting (ϕ)	Skewness	Kurtosis
Toe of Bluff	0.31 / 0.81	1.20	0.28	2.29
Mid-beach	1.54 / 0.34	0.80	-2.19	10.16
Shoreline	-0.01 / 0.93	1.71	0.00	1.35
3' Contour	1.54 / 0.34	1.19	-1.78	5.35
6' Contour	1.86 / 0.27	0.79	-2.64	12.13
9' Contour	2.03 / 0.25	0.70	-1.63	12.75
12' Contour	2.00 / 0.24	0.70	-1.62	8.74
15' Contour	2.03 / 0.25	1.03	-2.28	8.79
18' Contour	1.62 / 0.33	1.29	-1.31	3.95
21' Contour	2.30 / 0.20	0.54	-1.21	11.33

Historical Sediment Data

As part of the original Section 111 study in 1971, sediment samples were collected at several sites along the St. Joseph shoreline. These samples were collected prior to placement of dredged fill material in 1971. Data collection site R-11, which lies within the southern end of the feeder beach area, was one of the sites examined in 1971. Although data were collected at only one site used in current study, this information provides the closest representation of the actual native beach conditions with minimum contamination from artificial nourishment.

Sediment sampling occurred during April 1971 and represents winter beach characteristics. The 1971 study corresponds to the same time of year as the current study: April 1991. The historic sediments were collected using a surficial grab sampler at the following locations across the beach profile: backshore, foreshore, and 5-, 10-, 15-, and 20-ft depth contours. The composite grain size distribution for these materials is presented in Figure 8. The sediment at that time and specific location exhibits a poorly sorted distribution with a mean grain size of 1.09ϕ (0.47 mm) and a standard deviation of 1.85. Examination of the individual sample statistics (Appendix A) reveals that the coarsest and most poorly sorted material occurred at the foreshore with a mean grain size of 0.36ϕ (0.78 mm) and a standard deviation of 2.19. The backshore exhibits a well-sorted mean grain size of 1.64ϕ (0.32 mm) and standard deviation of

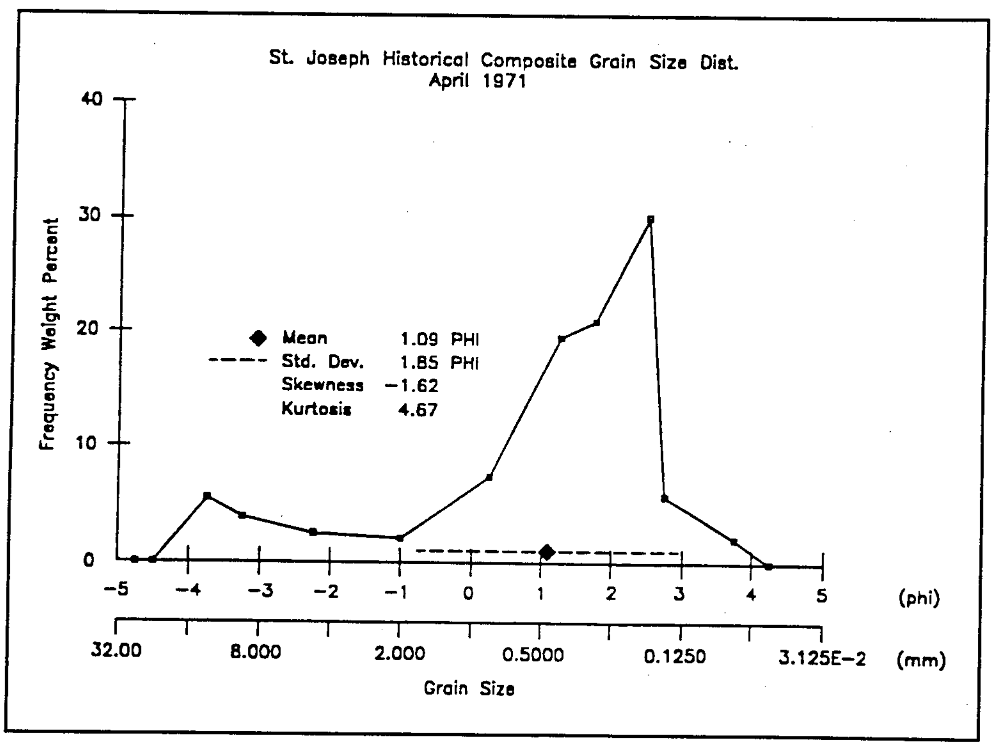

Figure 8. Historical composite grain size distribution for site R-11. Sampling occurred in April 1971 as part of the original Section 111 study

0.45. Lakeward of the foreshore, the mean grain size progressively decreases to 2.33ϕ (0.20 mm) at the 10-ft depth contour before abruptly increasing to poorly sorted (0.67ϕ (0.63 mm)) out to the 20-ft depth contour.

The 1971 composite exhibits a more poorly sorted and significantly larger mean grain size than the pre-fill composite of 1991. A comparison of grain size statistics between 1971 and 1991 can be seen in Table 4. The finer sediment characteristics of the 1991 composite may be an indication of the gradation bias resulting from the continuous placement of relatively fine-grained material from maintenance dredging of St. Joseph Harbor. However, one must also consider the possibility of differences in energy conditions prior to sampling for each time period.

Table 4
1971 and 1991 Grain Size Distribution Comparison

Parameter	April 1971	April 1991
Mean	1.09ϕ/0.47 mm	1.63ϕ/0.32 mm
Sorting (ϕ)	1.85	1.27
Skewness	-1.62	-1.14
Kurtosis	4.67	4.26

Shortcomings of Techniques Used

As indicated earlier, the feeder beach area at St. Joseph exhibits a pre-fill composite mean grain size of 1.63ϕ (0.32 mm). Further inspection of the composite distribution curve presented in Figure 7 shows a maximum grain size of -2.75ϕ (6.73 mm) and a minimum of 4.25ϕ (0.05 mm), ranging from small pebbles to coarse silt, according to the Wentworth scale. However, visual inspection of the study area reveals the presence of a wider range of sediment sizes. This visual discrepancy raises some questions as to the effectiveness of the sediment sampling methodologies, which were developed primarily for sandy beaches, in cases where highly variable and irregular ranges of sediment gradation exist, such as along the beaches of St. Joseph.

Additional samples collected within the project area reveal the extreme variations of sediment gradation that exist at St. Joseph. A single sample collected about 3.0 m (10 ft) from the waterline on 17 November 1993 from lag deposits of coarse-grained material on line R-8 exhibits a mean grain size of -3.49ϕ (11.30 mm) as shown in Figure 9. The coarse deposits shown in Figure 10 occurred between the sampling locations and would not have been sampled under the normal field survey procedures. Obtaining adequate amounts of very coarse sediment to perform valid sieve tests is difficult under field conditions. For example, if a sample of

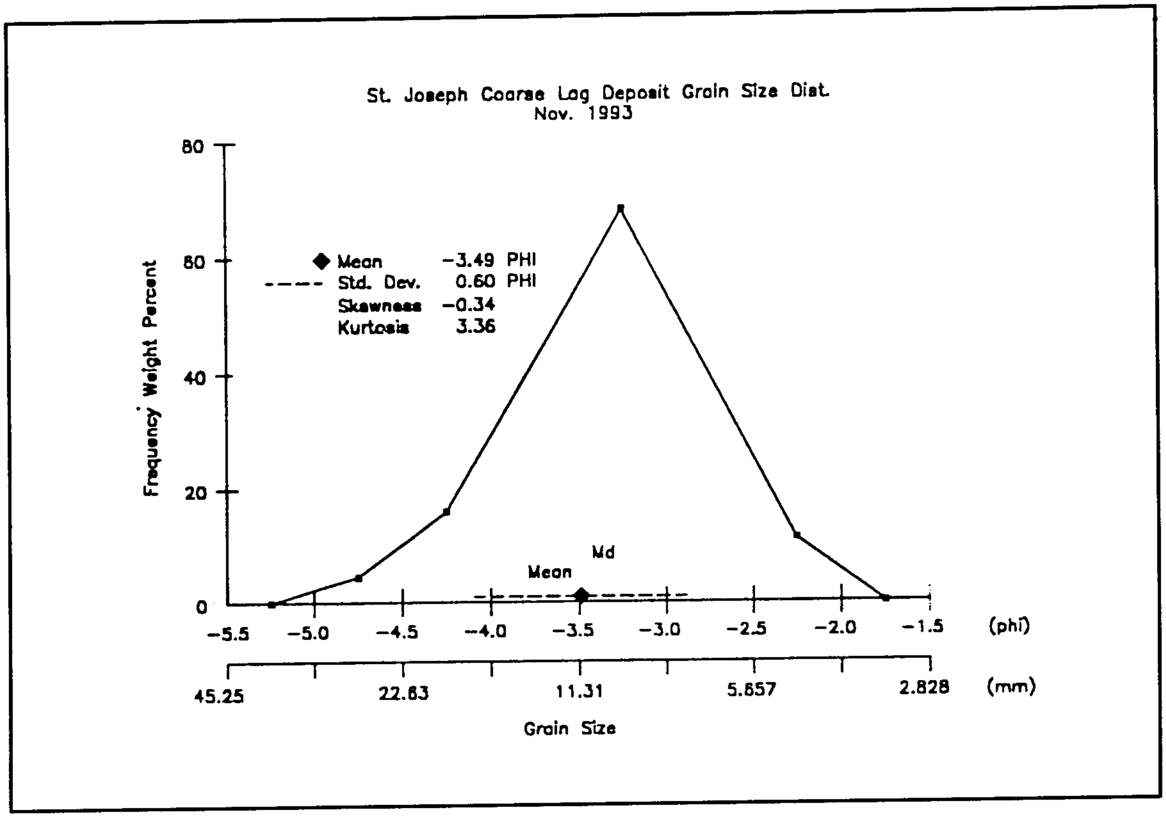

Figure 9. Grain size distribution from coarse lag deposit found along line R-8

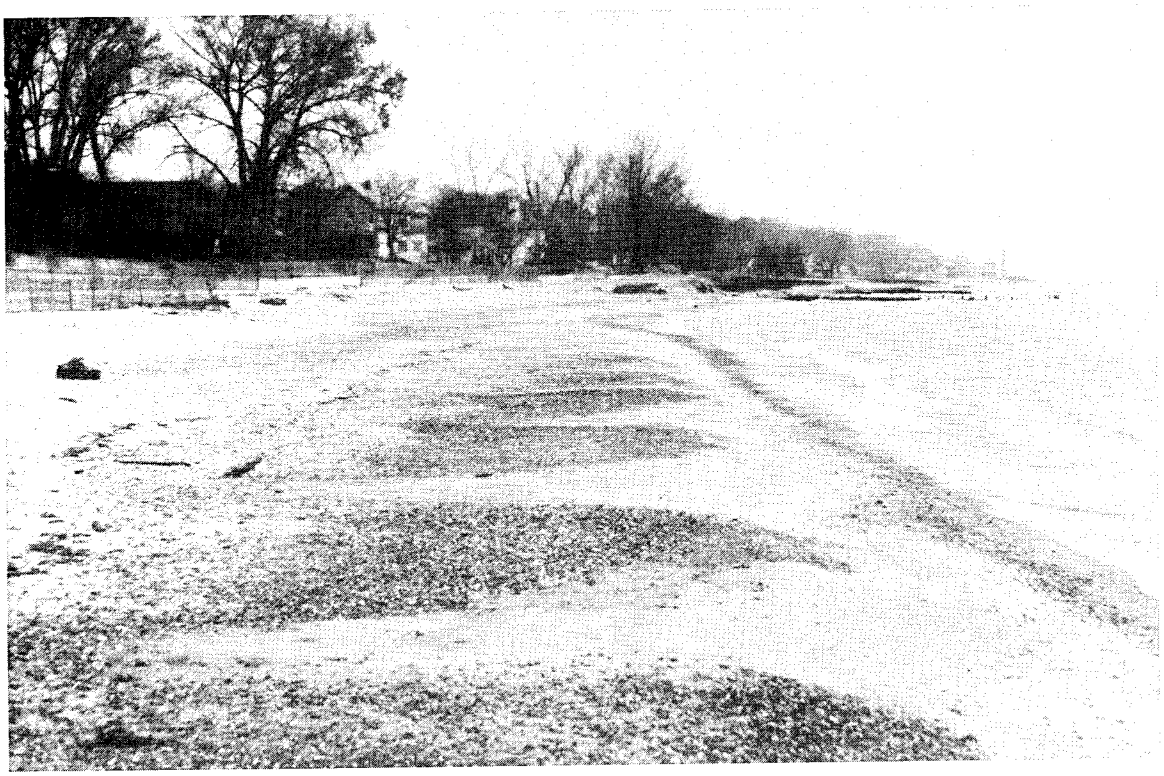

Figure 10. Example of coarse lag deposits on the beach along line R-8

the gravel with characteristics as shown in Figure 9 were collected, a quantity in excess of 50 kg would be required (Headquarters, U.S. Army Corps of Engineers, in preparation).

An example of the opposite extreme is represented by the presence of cohesive glacial till material that constitutes the geologic foundation of this area. Ground penetrating radar surveys have identified nearshore areas within the study site where till is either exposed or covered by only a thin veneer of sand and gravel.[1] A sample of the lakebed till was collected along line R-14 using a 6-ton clam bucket operated from a crane barge. Figure 11 clearly shows the contact surface of the till, which consists of a mixture of coarse sand held together by a cohesive matrix of sandy-clayey-silt. Results of a grain size analysis of the till are presented in Figure 12. The analysis reveals a poorly sorted mixture with a mean grain size of 6.27ϕ (0.01 mm).

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1 Personal Communication, 1993, W. Sauck, Department of Geophysics, Western Michigan University, Kalamazoo, MI.

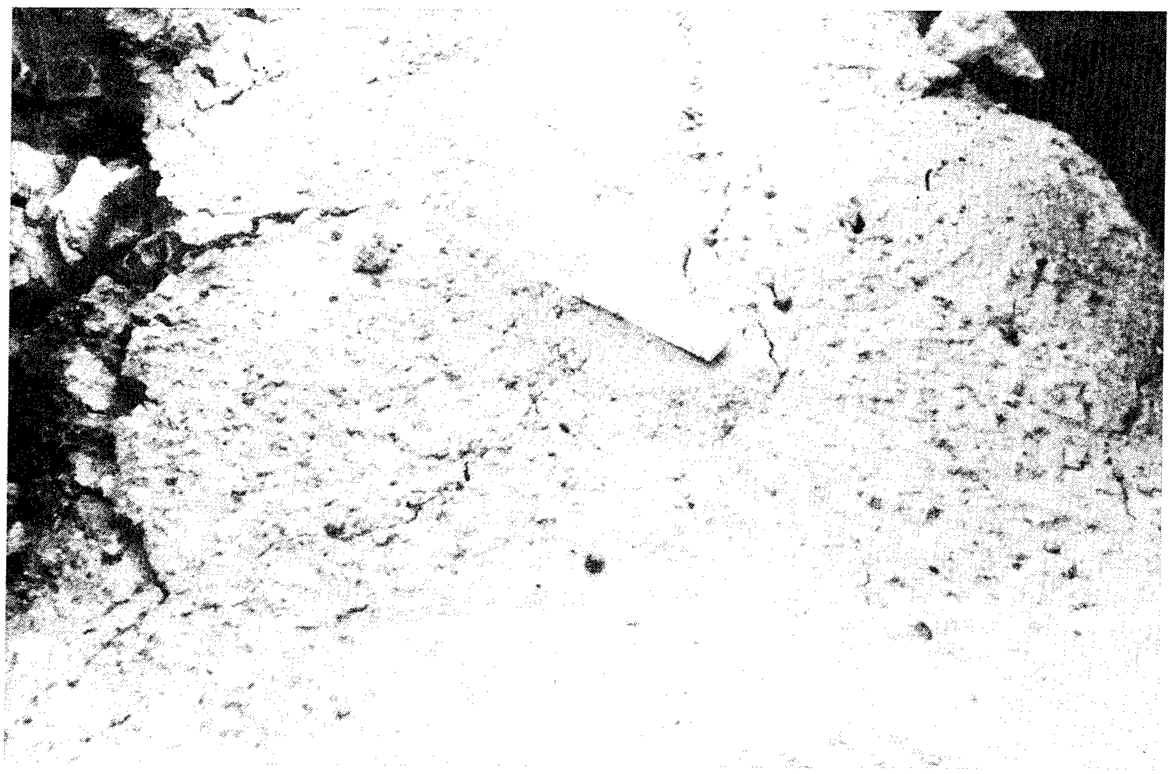

Figure 11. View of the glacial till as it was collected using a large clam bucket operated from a crane barge

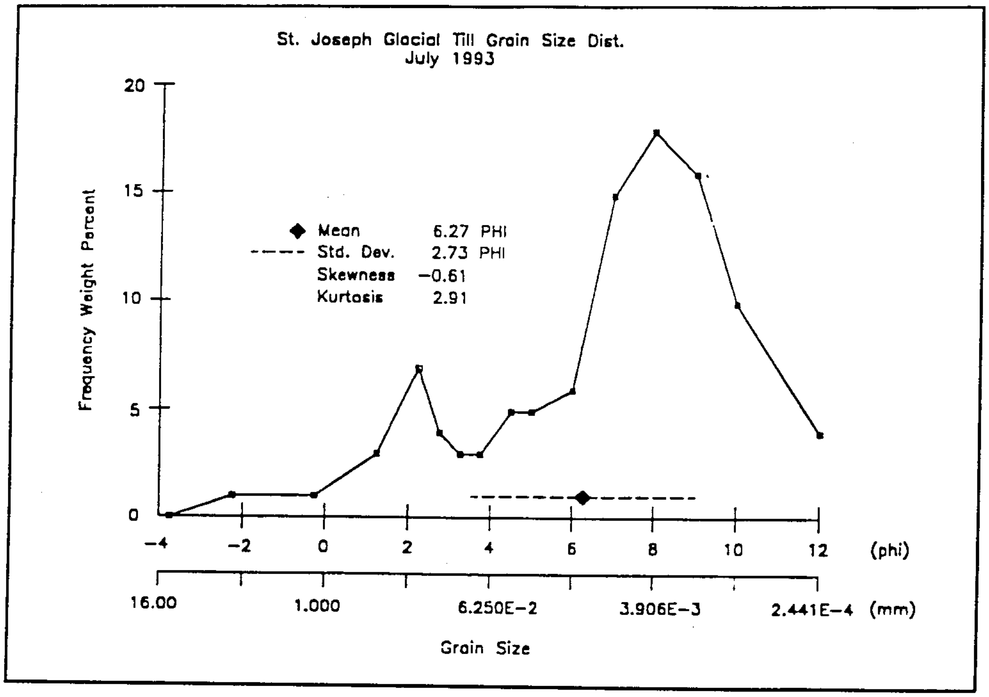

Figure 12. Grain size distribution of the glacial till lakebed material

A comparison of the grain size distribution among the pre-fill composite, coarse lag deposit, and glacial till lakebed material can be examined in Figure 13. The comparison illustrates that the extreme upper and lower limits of sediment sizes exhibited by the coarse lag material and glacial till are deficient from the native/pre-fill beach sediment characterization for St. Joseph. It is likely that the deficiencies result from sampling methods used during this study for native beach characterization and may not provide the capabilities necessary to adequately represent extremely wide and irregular ranges of sediment sizes.

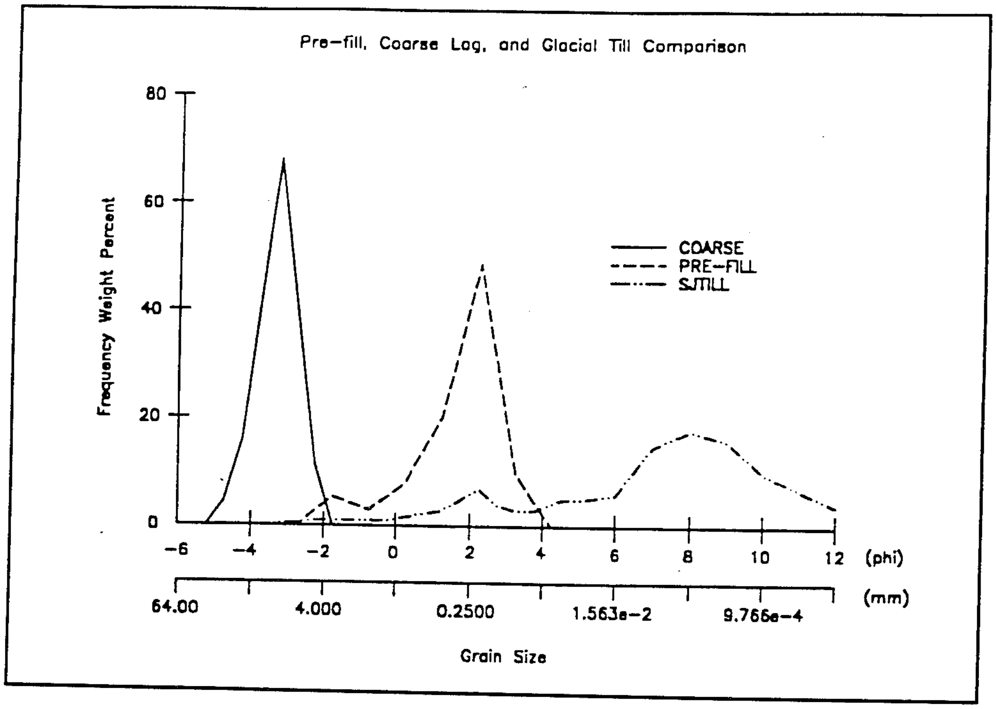

Figure 13. Comparison of the grain size distributions among the pre-fill composite, coarse lag deposits, and glacial till

3 Accepted Coastal Sediment Sampling Approach

Sampling methodology and sampling locations are important criteria in accurately characterizing the native sediment in a study area. The sampling methodology section discusses the various types of instruments which can be used to collect samples, both surficially, and sub-surficially, while the sampling location section concerns the framework or positioning of sediment samples.

In planning a sediment sampling program, the areal extent, repetition, (i.e. tidal, storm, and seasonal conditions), and whether surficial or subsurficial samples are required must be considered. Establishing a sediment sampling program is dependent upon knowledge of the study area, scientific insight, and project budget. A physical sampling program, particularly subsurface information, should be complemented with geologic data to provide additional information about the geology of the study area. Topographic information can be obtained from bathymetric surveys and side-scan sonar. Subsurface information can be provided using ground penetrating radar and sub-bottom seismic profiling.

Methodology

Sediment sampling techniques for determining beach characteristics can be divided into two general methods: surficial and subsurface. The most commonly used tools to obtain surficial sediments are the grab samplers. These include the Ekman or Ponar, Petersen, orange peel, shipek (Palermo, Montgomery and Poindexter 1978), Van Veen, and clamshell grab samplers (Canadian Department of Fisheries and the Environment 1978). Some examples of these instruments are illustrated in Figure 14. The basic design of these devices consists of a set of jaws that snap shut when the sampler hits the sea bottom, thus collecting a sample. The sediments collected by these instruments are limited to surface sediments and

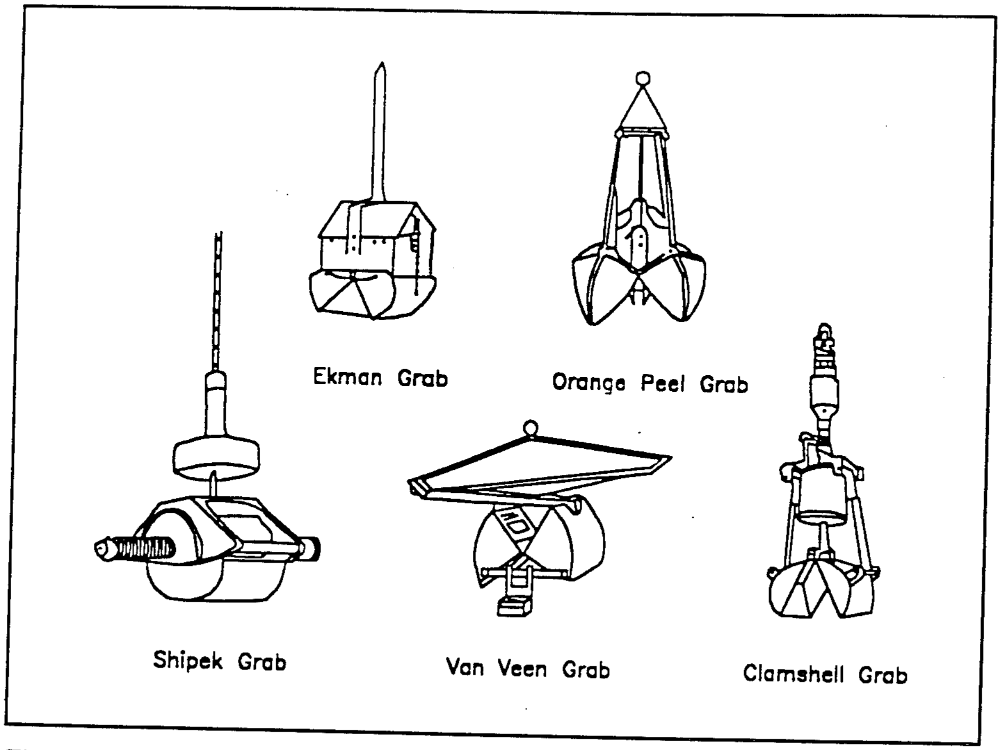

Figure 14. Various types of commonly used grab samplers

tend to be mixed and disturbed by the sampling process. These devices perform best when sampling unconsolidated sandy material and are not very effective when collecting large grain sizes or materials of a firm or cohesive nature.

Subsurface samples are collected using various coring devices, including vibracores, gravity cores, piston cores, short cores, electrokinetic cores, diver cores, can or box cores, and hand augers. The depth of core penetration is dependent upon the geological nature of the sampling area and may not be adequate where consolidated sub-bottoms and very coarse materials exist. The field time involved in collecting cores is greater than collecting surface samples and may not lend itself practical where time and money constraints are involved.

Coring devices force a hollow cylindrical core barrel into the subsurface. The core barrel fills up with sediment equaling the depth of penetration. These coring devices can be used with or without retractable plastic liners where the use of a liner prevents having to destroy the core tube in order to analyze the sediment sample. These devices perform best when sampling unconsolidated materials and may be restricted by the presence of coarse grain sizes or sediments of a firm, cohesive nature. See the referenced articles for more information on using individual coring mechanisms and resultant field investigations.

Vibracorers, or cores which vibrate into the subsurface, are the most widely used type of corer in shallow water (to -8 m (-26.2 ft) mlw) coastal and marine environments. There are several types of vibracores, ranging in size and cost depending upon application. Inexpensive, diverless vibracoring units (i.e., employed by Smith (1991) and Smith and Clausner (1993)) used a refinement of a coring system developed by Lanesky et al. (1979) and Finkelstein and Prins (1981). More expensive vibracorers, such as the one shown in Figure 15, often result in greater penetration and recovery.

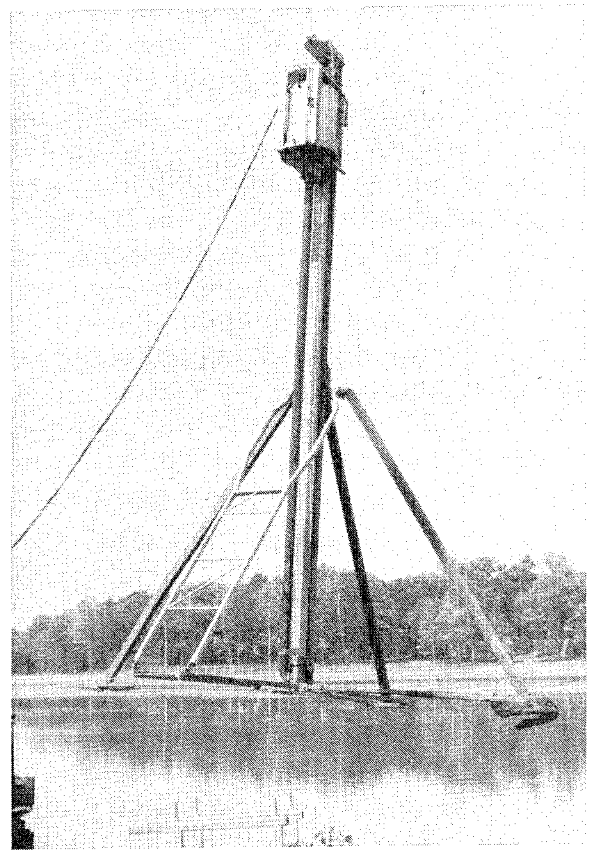
Figure 15. Commercially available vibracorer

A clam bucket operated from a crane barge was used at St. Joseph to sample the highly cohesive glacial till lakebed foundation. This method is particularly useful in environments with hard substrate bottoms or where large samples are required. However, this method cannot accurately discern stratigraphic horizons. The high cost of a barge and heavy lifting equipment would make it prohibitive for most projects.

Sampling Locations

In designing a sediment sampling program, the framework and location of both surficial and sub-surficial samples are of crucial importance to most accurately define sediment characteristics. Sediment sampling schemes vary according to coastal environment and purpose of the sediment sampling program. Ideally, surficial sediment samples should be collected concurrently with profile surveys at monthly intervals throughout the year to define seasonal and storm changes (Stauble 1991b). Because sampling this frequently may be cost prohibitive, the collection of winter and summer sediment samples and profile surveys provides a minimum amount of information to characterize the range of grain size distributions and active profile changes expected as a result of seasonal variations (SPM 1984).

In the past, cross-shore sampling programs have taken sediment samples at specific elevations (i.e., +5, +2.5, 0, -2.5, -5 ft, etc.). However, Stauble and Hoel (1986) suggest that sediment samples be collected at morphologic zones along the profile such as at dune crest, dune base, berm crest, high tide line (berm crest and high tide line may be similar in some localities), mid-tide, low tide/swash platform, trough, bar crest, -1.5 m (-5 ft) (mlw), -3.0 m (-10 ft) (mlw), -4.6 m (-15 ft) (mlw), -6.1 m (-20 ft) (mlw), -7.6 m (-25 ft) (mlw), -9.1 m (-30 ft) (mlw) as shown in Figure 16. By sampling at specific morphologic locations, Stauble and Hoel state that sediment grain size distributions can be directly compared with subsequent surveys. There is no unique way to determine the number of samples needed to effectively describe sediment characteristics of an environment. The sampling program must be planned based on the unique conditions at that environment. Important factors include the size of the area, a priori information on sediment characteristics, and beach morphology.

Krumbein and Slack (1956) suggest sampling at each of the natural zones of the beach and present three variations of stratified random sampling. The first variation states that the number of samples per zone is proportional to the zone width. Thus, the narrowest zones will have the fewest samples while the wider zones will have more samples. This variation assures that samples of each zone are included in the weighted mean proportional to its width. The second variation is to have an equal number of samples from each zone, regardless of zone width. This variation assures that each zone is included in the final estimate, but it takes no account of the relative zone weighting the sampling plan. The third variation distributes the samples over the zone in proportion to the relative variability with respect to sediment distributions in each zone. That is, if the nearshore is four times as variable as the foreshore, then four

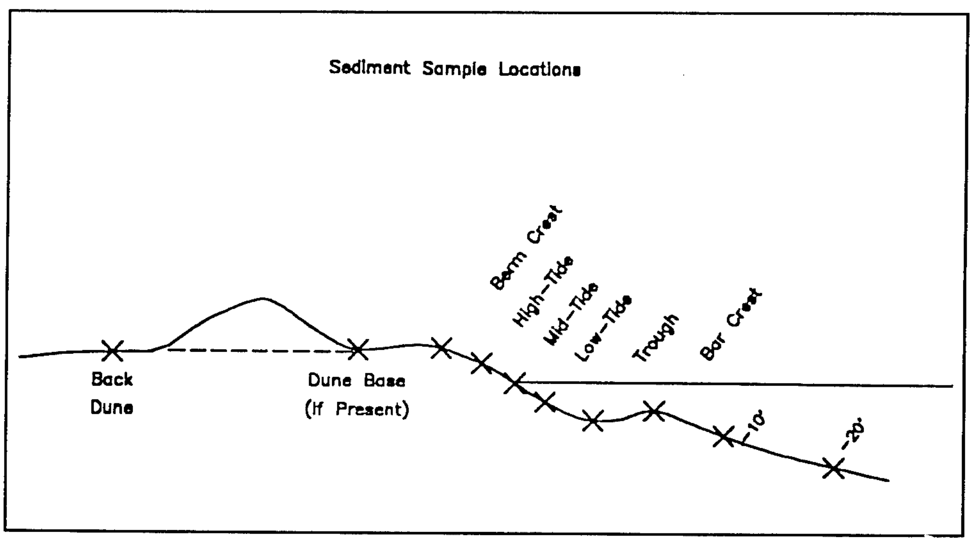

Figure 16. Sediment sample locations across the profile as described by Stauble and Hoel (1986)

times as many samples would be taken in the nearshore as in the foreshore, regardless of zone width.

Anders, Underwood, and Kimball (1987) determined that while there is no relationship between standard deviation (sorting) and the number of samples, there is a clear relationship between mean grain size and the number of samples required to characterize the sub-aerial beach, which can also be utilized for specific sub-aerial and sub-aqueous environments (Figure 17). In general, they determined that coarse-grained beaches and sub-environments require more samples to accurately characterize the conditions than do beaches and sub-environments with fine-grained material.

In addition, Anders, Underwood, and Kimball (1987), in determining sediment characteristics for a planned beach nourishment at Ocean City, Maryland, statistically determined the number of samples necessary to accurately characterize the sub-aerial beach. Their results showed that considerably fewer samples are required to accurately characterize the sediment distribution if sampling programs are designed parallel to the shoreline rather than the usual practice of shore-normal positioning. They divided the beach into cross-shore sub-environments. This reorienting of the sampling program to an alongshore position can effectively reduce the number of samples necessary to optimally describe sediment distributions along a uniform beach or sub-environment.

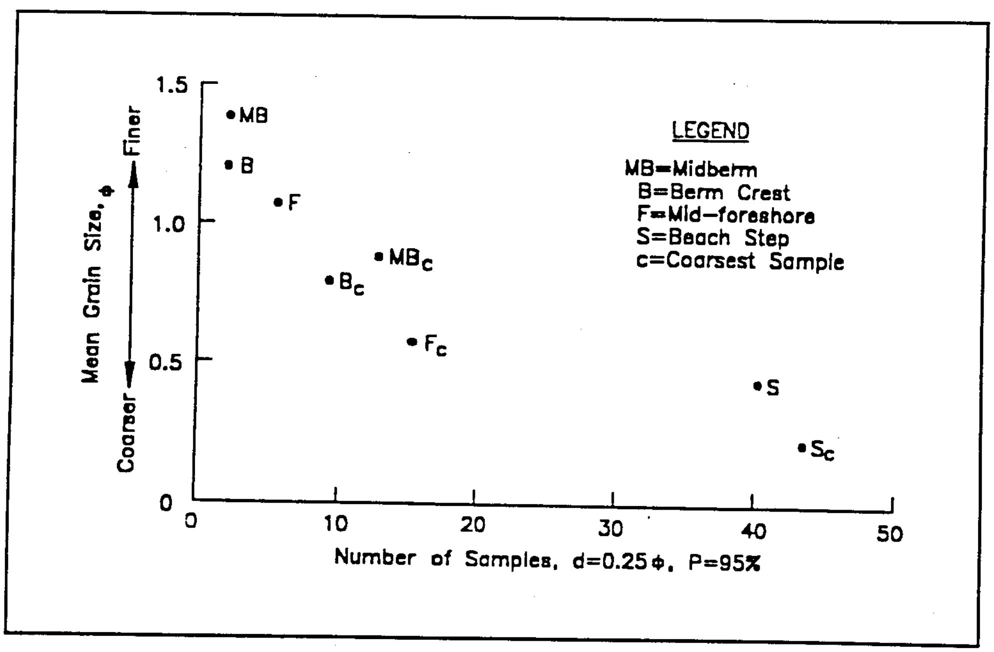

Figure 17. Relationship between mean grain size and number of samples required to maintain a 0.25-φ accuracy at 95-percent confidence

Krumbein (1954) states that a distinction should be made between purposive selection and random sampling. In purposive selection sampling, samples are restricted to places that are typical of the conditions being sampled. A random sample calls for some process of randomization to be applied to the procedure of collecting the sample. In addition to purposive selection, Krumbein (1954) states four sampling procedures for random sampling at a study area, including: (a) simple random sampling; (b) stratified sampling or random with respect to cells; (c) systematic sampling with respect to cells; and (d) stratified systematic sampling. For demonstrative reasons, each sampling method has 16 samples. Simple random sampling is a method whereby the entire study area is considered as one unit (Figure 18s, after Krumbein (1954)). Samples are randomly picked from the entire area. That is, every sample within the entire study area has an equal chance of being selected. In stratified sampling, the entire study area is divided into 16 cells of similar area (Figure 18b). Samples are then randomly picked with respect to each individual cell within the entire study area. That is, every sample within each individual cell within the entire study area has an equal chance of being selected. In systematic sampling, a random sample is taken from one (for purposes of clarification, the upper left or northwest cell) of the cells of the study area. This same position is now sampled in each of the remaining cells (Figure 18c). In stratified systematic sampling, a random sample is taken from one of the cells of the study area. Subsequently, the vertical, or north-south coordinates, are applied to the upper east-west row of cells, while the east-west coordinates for these cells are randomly picked (Figure 18d). Conversely, the horizontal, or east-west coordinates from the

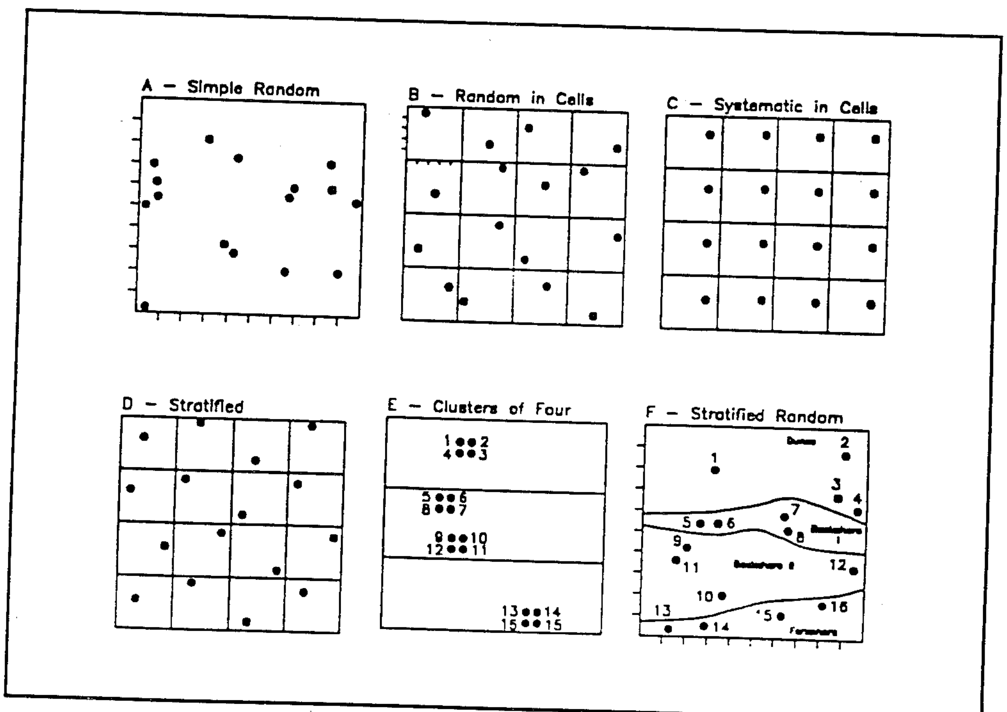

Figure 18. Methods of random sediment sampling developed by Krumbein (1954)

original cell are applied to the leftmost north-south row of cells, while the north-south coordinates are randomly picked.

Krumbein and Slack (1956) present three additional types of random samples as employed at a study site, including (a) clusters of four; and (b) stratified random. In the cluster-of-four sampling plan (Figure 18e), the samples are taken in clusters of four. Each row has one cluster, the position of which was randomized. The stratified random sampling method (Figure 18f) is based upon geomorphic zones of the beach area. In this methodology, four samples of each zone are collected randomly.

The depth of cores is dependent upon the geological nature of the region, and depth of excavation or dredging if dredging is included in the project design. The number of sediment samples in that case should be able to effectively characterize the regional geology for the area and/or each specific sub-environment.

4 Suggested Sampling Method Variations

Realistic determination of native beach characteristics in areas exhibiting highly irregular sediment zonations and wide ranges of sediment sizes, such as St. Joseph, requires sampling programs based on the local geology, meteorology, and sediment characteristics. Planning a sediment sampling program depends upon knowledge of a study area, scientific insight, and budget. Collection of samples should be complemented with existing information providing the greatest amount of knowledge with respect to geological nature of the study area. Additional information may include side-scan sonar mosaics, subsurface maps based on geophysical tools (Ground Penetrating Radar and sub-bottom seismic profiling), and existing bathymetric data. The sampling variations described in this section are suggestions and have not been field tested.

Temporal Sampling

As previously stated, it would be most beneficial to obtain samples at monthly intervals throughout the year to define seasonal and storm changes. Sampling this frequently may be cost prohibitive. Collection of seasonal sediment samples provides a minimum amount of information to characterize the range of grain size distributions. However, winter beach characteristics are of greatest concern in the Great Lakes. As high energy conditions remove finer-grained materials from the beach, the coarser sediments are left behind to protect against the winter wave attack. When dealing with erosion mitigation projects in the Great Lakes, it is desirable to know the characteristics of material needed to protect or armor the beaches during these high energy winter periods. If time and budget constraints prevent monthly or seasonal sediment sampling for determining native beach characteristics, an effort should be made for sampling to occur during the early spring when harsh weather conditions subside and winter beach characteristics are still prominent.

Sampling Locations

In areas exhibiting regular sediment zonations and size gradations, every effort should be made to adhere to the sampling location scheme previously described in the monitoring program section. Where highly irregular characteristics occur, efforts should be made to identify the sediment zonations across the profile. This is a simple process and can be accomplished visually on the subaerial beach and under water out to wading depth. It is not as easily accomplished, however, for the deeper offshore segment of the profile. If project budgets permit, instruments such as side-scan sonar or ground penetrating radar can be utilized to aid in identifying surface sediment zonations on the deeper segments of the profile.

After identifying the sediment zonations, it is suggested that each zone be treated as natural zones described by Krumbein and Slack (1956). Surface samples could then be obtained with the number of samples proportional to the zone width, i.e., the widest zones having more samples than the narrow zones. This method would assure that each zone is weighted proportionally to its width.

Grain Size Analysis

Standard methods should be followed while performing the sediment grain size analysis. Care should be taken to collect adequate amounts of coarse sediment so that valid sieve tests can be performed. Samples of gravel with characteristics as presented in Figure 9 would be quite large (in excess of 50 kg (110 lb)). Numerous samples of this size are not practical to transport from the field to the laboratory for analysis. It is recommended that an array of sieves large enough to handle such sediment samples be used in the field. This would alleviate the high cost of transporting large samples. Finer grained material can be collected and sent to a laboratory for analysis.

5 Summary and Conclusions

The accurate representation of native beach characteristics is essential to understanding the behavior of coastal areas in response to coastal structures and erosion mitigation projects. The shoreline along St. Joseph, Michigan, and vicinity is one of many sites throughout the Great Lakes exhibiting highly irregular sediment zonations and wide ranges of sediment size gradation as opposed to classic sandy beach characteristics. These unique features do not conform to sampling techniques developed primarily for sandy beach environments.

The most commonly used surficial sampling methods can only collect data representative of recent depositional events, and thus require repetitive sampling to obtain information representative of the beach during all seasons (Anders and Hansen 1990). Coring techniques can be used to provide temporal information by collecting sub-surface samples representing various depositional events. Sampling in this manner is highly dependent on the geologic characteristics of the sampling area, requires greater field time, and may not be feasible if time and money constraints are a factor. However, if geologic, time, and budget constraints provide limited sampling opportunities, knowledge of winter beach conditions through surficial sampling can be particularly useful since the more stable coarser grains are usually present on the beach during this time, forming the line of defense against the winter wave attack.

At St. Joseph, Michigan, sediment sampling prior to fill placement was limited by budget and time constraints. Sampling occurred in early spring and represents the winter beach environment. Determination of the true "native" beach characteristics for St. Joseph and vicinity has been obscured by the ongoing fill history of the area over the previous 24 years. The composite sediment analysis performed under this study represents at best "pre-fill" beach characteristics for the feeder beach area. Data available for St. Joseph from the original Section 111 study allowed for a limited comparison of composite grain size distributions for the feeder beach area. Finer sediment characteristics exhibited during the recent samples as compared to the historical samples may be an indication of the biases introduced by past fills.

Analysis of later single samples reveals extreme variations in sediment zonations and gradation not represented in the pre-fill composite sediment size distribution. It is likely that the deficiencies are a result of the methods used in sampling this area. This raises serious doubts about the validity of techniques and methodologies developed primarily for sandy shorelines being employed in areas where highly irregular zonations and wide sediment gradations exist, such as in the Great Lakes. It is evident that a sediment sampling program based on conditions in the Great Lakes is necessary, and sampling techniques should be based on the unique sediment characteristics and natural variations in geology for this area in an effort to provide realistic representation of native beach characteristics.

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Appendix A
Sediment Data and Statistics

Appendix A contains detailed statistical information on the composite sediment data used in this report. The detailed information contained herein was compiled using the Automated Coastal Engineering System (ACES) software. Data presented include grain size characteristics for the following:

a. Coarse fill composite.

b. Pre-fill beach composite.

c. Composite for each beach zonation used in the analysis (toe of bluff thru 21 ft depth) contour.

d. Composite data for each profile line (R-8 thru R-12).

e. Historical "native beach" composite from April 1971.

f. Coarse lag deposit along line R-8.

g. Glacial till material.

Coarse Fill Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	57.67	23.42	0.00	17.70	1.20	0.00
Unified	47.22	10.45	23.42	17.70	1.20	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		-1.28 phi	2.434mm
Mean Diameter	-1.21 phi	-0.81 phi	2.311mm
Standard Deviation	2.69 phi	2.81 phi	
Skewness	0.17	0.13	
Kurtosis	1.73	0.69	

Composite: SJFILL
Title: St. Joseph Coarse Fill Composite Grain Size Dist.
Date Analyzed: 11/19/93
Analyzer: LEP
Comment:
Total Weight: 100.00
Type of Samples: backshore
Samples in Composite: 1
Top of Composite: 0.000 feet
Bottom of Composite: 0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
-----	128.0	-7.00	0.000	8.00	2.38	-1.25	10.453	200.0	0.074	3.75	1.408
-----	26.91	-4.75	15.096	30.00	0.59	0.75	23.424	270.0	.0526	4.25	1.198
-----	13.45	-3.75	16.012	100.0	0.149	2.75	16.294	400.0	.0372	4.75	0.000
4.00	4.76	-2.25	16.113								

Pre-fill Beach Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	5.38	10.75	20.41	63.46	0.00	0.00
Unified	0.00	5.38	31.16	63.46	0.00	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.15 phi	0.226mm
Mean Diameter	1.63 phi	1.55 phi	0.322mm
Standard Deviation	1.27 phi	1.26 phi	
Skewness	-1.14	-0.73	
Kurtosis	4.26	1.96	

Composite: SJPREFILL
Title: St. Joseph Pre-fill Composite Grain Size Dist.
Date Analyzed: 11/19/93
Analyzer: LEP
Comment:
Total Weight: 100.00
Type of Samples: backshore
Samples in Composite: 1
Top of Composite: 0.000 feet
Bottom of Composite: 0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
3.00	6.73	-2.75	0.000	20.00	0.84	0.25	7.833	140.0	0.105	3.25	9.965
6.00	3.36	-1.75	5.377	40.00	0.42	1.25	20.409	200.0	0.074	3.75	4.787
12.00	1.68	-0.75	2.921	70.00	0.21	2.25	48.708	270.0	.0526	4.25	0.000

Toe of Buff Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	5.76	59.85	23.91	10.40	0.08	0.00
Unified	0.00	5.76	62.48	31.63	0.12	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		-0.31 phi	1.236mm
Mean Diameter	0.31 phi	0.36 phi	0.804mm
Standard Deviation	1.20 phi	1.21 phi	
Skewness	0.28	0.53	
Kurtosis	2.29	0.87	

Composite: Bluff Toe
Title: St. Joseph Toe of Bluff Composite Grain Size Dist.
Analyzer:
Comment:
Date Analyzed: 12/08/93
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
bluff toe	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	0.332	80.00	0.177	2.50	2.559
5.00	4.00	-2.00	5.093	25.00	0.71	0.50	0.490	100.0	0.149	2.75	0.719
6.00	3.36	-1.75	0.165	30.00	0.59	0.75	0.780	120.0	0.125	3.00	0.207
7.00	2.83	-1.50	0.101	35.00	0.50	1.00	1.560	140.0	0.105	3.25	0.108
8.00	2.38	-1.25	0.222	40.00	0.42	1.25	2.637	170.0	0.088	3.5	0.059
10.00	2.00	-1.00	0.184	45.00	0.35	1.50	4.758	200.0	0.074	3.75	0.049
12.00	1.68	-0.75	0.170	50.00	0.30	1.75	7.464	230.0	.0625	4.00	0.045
14.00	1.41	-0.50	0.280	60.00	0.25	2.00	9.050	270.0	.0526	4.25	0.080
16.00	1.19	-0.25	56.234	70.00	0.21	2.25	6.653				
18.00	1.00	0.00	0.000								

Mid-beach Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	2.82	9.66	63.75	23.67	0.09	0.00
Unified	0.00	2.82	18.21	78.82	0.14	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		1.68 phi	0.312mm
Mean Diameter	1.55 phi	1.64 phi	0.342mm
Standard Deviation	0.80 phi	0.58 phi	
Skewness	-2.25	-0.22	
Kurtosis	10.57	1.32	

Composite: Mid-beach
Title: St. Joseph Mid-beach Composite Grain Size Dist.
Analyzer:
Comment:
Date Analyzed: 12/08/93
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
Mid-beach	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	0.773	80.00	0.177	2.50	6.384
5.00	4.00	-2.00	1.246	25.00	0.71	0.50	1.138	100.0	0.149	2.75	1.933
6.00	3.36	-1.75	0.268	30.00	0.59	0.75	1.616	120.0	0.125	3.00	0.585
7.00	2.83	-1.50	0.505	35.00	0.50	1.00	4.811	140.0	0.105	3.25	0.236
8.00	2.38	-1.25	0.456	40.00	0.42	1.25	8.553	170.0	0.088	3.5	0.102
10.00	2.00	-1.00	0.349	45.00	0.35	1.50	15.238	200.0	0.074	3.75	0.070
12.00	1.68	-0.75	0.392	50.00	0.30	1.75	18.824	230.0	.0625	4.00	0.054
14.00	1.41	-0.50	0.644	60.00	0.25	2.00	21.138	270.0	.0526	4.25	0.091
16.00	1.19	-0.25	0.285	70.00	0.21	2.25	14.309				
18.00	1.00	0.00	0.000								

Shoreline Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand: Coarse	Sand: Medium	Sand: Fine	Silt	Clay
Wentworth	41.25	16.29	30.16	12.29	0.00	0.00
Unified	0.00	41.25	20.30	38.42	0.01	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		0.17 phi	0.890mm
Mean Diameter	-0.01 phi	0.00 phi	1.005mm
Standard Deviation	1.71 phi	1.66 phi	
Skewness	0.00	-0.10	
Kurtosis	1.32	0.51	

Composite: Shoreline
Title: St. Joseph Shoreline Composite Grain Size Dist.
Analyzer
Comment
Date Analyzed: 12/08/93
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
Shoreline	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	2.103	80.00	0.177	2.50	2.939
5.00	4.00	-2.00	21.250	25.00	0.71	0.50	2.108	100.0	0.149	2.75	1.009
6.00	3.36	-1.75	6.437	30.00	0.59	0.75	1.677	120.0	0.125	3.00	0.287
7.00	2.83	-1.50	4.517	35.00	0.50	1.00	3.072	140.0	0.105	3.25	0.148
8.00	2.38	-1.25	5.799	40.00	0.42	1.25	4.012	170.0	0.088	3.5	0.059
10.00	2.00	-1.00	3.251	45.00	0.35	1.50	6.516	200.0	0.074	3.75	0.020
12.00	1.68	-0.75	2.617	50.00	0.30	1.75	10.217	230.0	.0625	4.00	0.010
14.00	1.41	-0.50	3.439	60.00	0.25	2.00	9.410	270.0	.0526	4.25	0.010
16.00	1.19	-0.25	1.276	70.00	0.21	2.25	7.817				
18.00	1.00	0.00	0.000								

3' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand: Coarse	Sand: Medium	Sand: Fine	Silt	Clay
Wentworth	7.50	9.31	37.45	45.72	0.02	0.00
Unified	0.00	7.50	12.35	80.13	0.03	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		1.94 phi	0.260mm
Mean Diameter	1.55 phi	1.74 phi	0.340mm
Standard Deviation	1.18 phi	0.99 phi	
Skewness	-1.84	-0.55	
Kurtosis	5.60	2.26	

Composite: 3' depth
Title: St. Joseph 3' Contour Composite Grain Size Dist.
Analyzer
Comment
Date Analyzed: 12/08/93
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
3'CONTOUR	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	1.155	80.00	0.177	2.50	15.378
5.00	4.00	-2.00	2.910	25.00	0.71	0.50	1.097	100.0	0.149	2.75	5.457
6.00	3.36	-1.75	1.149	30.00	0.59	0.75	0.982	120.0	0.125	3.00	1.548
7.00	2.83	-1.50	1.005	35.00	0.50	1.00	2.050	140.0	0.105	3.25	0.468
8.00	2.38	-1.25	1.317	40.00	0.42	1.25	3.037	170.0	0.088	3.5	0.110
10.00	2.00	-1.00	1.115	45.00	0.35	1.50	5.630	200.0	0.074	3.75	0.035
12.00	1.68	-0.75	1.334	50.00	0.30	1.75	10.394	230.0	.0625	4.00	0.012
14.00	1.41	-0.50	2.004	60.00	0.25	2.00	18.392	270.0	.0526	4.25	0.017
16.00	1.19	-0.25	0.687	70.00	0.21	2.25	22.718				
18.00	1.00	0.00	0.000								

6' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)

	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	2.37	5.05	40.57	51.99	0.02	0.00
Unified	0.00	2.37	7.54	90.05	0.04	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.02 phi	0.247mm
Mean Diameter	1.86 phi	1.98 phi	0.275mm
Standard Deviation	0.78 phi	0.55 phi	
Skewness	-2.71	-0.28	
Kurtosis	12.67	1.52	

Composite: 6' Depth
Title: St. Joseph 6' Contour Composite Grain Size Dist.
Analyzer
Comment
Date Analyzed: 12/08/93
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
6'CONTOUR	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	0.731	80.00	0.177	2.50	17.849
5.00	4.00	-2.00	0.790	25.00	0.71	0.50	0.673	100.0	0.149	2.75	6.464
6.00	3.36	-1.75	0.347	30.00	0.59	0.75	0.779	120.0	0.125	3.00	1.831
7.00	2.83	-1.50	0.304	35.00	0.50	1.00	1.708	140.0	0.105	3.25	0.576
8.00	2.38	-1.25	0.486	40.00	0.42	1.25	2.487	170.0	0.088	3.5	0.144
10.00	2.00	-1.00	0.443	45.00	0.35	1.50	6.021	200.0	0.074	3.75	0.053
12.00	1.68	-0.75	0.342	50.00	0.30	1.75	11.305	230.0	.0625	4.00	0.021
14.00	1.41	-0.50	0.539	60.00	0.25	2.00	20.753	270.0	.0526	4.25	0.021
16.00	1.19	-0.25	0.278	70.00	0.21	2.25	25.055				
18.00	1.00	0.00	0.000								

9' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)

	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	0.93	3.30	36.09	57.79	1.88	0.00
Unified	0.00	0.93	5.41	91.58	2.07	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.09 phi	0.235mm
Mean Diameter	2.03 phi	2.06 phi	0.245mm
Standard Deviation	0.69 phi	0.46 phi	
Skewness	-1.64	-0.14	
Kurtosis	13.17	1.30	

Composite: 9' Depth
Title: St. Joseph 9' Contour Composite Grain Size Dist.
Analyzer
Comment
Date Analyzed: 12/08/93
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
9'CONTOUR	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	0.367	80.00	0.177	2.50	19.692
5.00	4.00	-2.00	0.291	25.00	0.71	0.50	0.410	100.0	0.149	2.75	7.163
6.00	3.36	-1.75	0.211	30.00	0.59	0.75	0.513	120.0	0.125	3.00	2.062
7.00	2.83	-1.50	0.113	35.00	0.50	1.00	1.182	140.0	0.105	3.25	0.761
8.00	2.38	-1.25	0.146	40.00	0.42	1.25	2.111	170.0	0.088	3.5	0.286
10.00	2.00	-1.00	0.173	45.00	0.35	1.50	4.750	200.0	0.074	3.75	0.184
12.00	1.68	-0.75	0.308	50.00	0.30	1.75	9.457	230.0	.0625	4.00	0.189
14.00	1.41	-0.50	0.372	60.00	0.25	2.00	19.773	270.0	.0526	4.25	1.884
16.00	1.19	-0.25	0.146	70.00	0.21	2.25	27.455				
18.00	1.00	0.00	0.000								

12' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand: Coarse	Sand: Medium	Sand: Fine	Silt	Clay
Wentworth	0.67	6.73	31.36	61.17	0.06	0.00
Unified	0.00	0.67	10.94	88.22	0.18	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.13 phi	0.229mm
Mean Diameter	2.01 phi	2.04 phi	0.248mm
Standard Deviation	0.69 phi	0.60 phi	
Skewness	-1.63	-0.25	
Kurtosis	8.98	1.25	

Composite	Title	Date Analyzed
12' Depth	St. Joseph 12' Contour Composite Grain Size Dist.	12/08/93
Analyzer	Comment	Total Weight 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
12'CONTOUR	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	0.533	80.00	0.177	2.50	21.056
5.00	4.00	-2.00	0.231	25.00	0.71	0.50	0.969	100.0	0.149	2.75	10.614
6.00	3.36	-1.75	0.081	30.00	0.59	0.75	1.227	120.0	0.125	3.00	4.387
7.00	2.83	-1.50	0.048	35.00	0.50	1.00	3.299	140.0	0.105	3.25	1.948
8.00	2.38	-1.25	0.183	40.00	0.42	1.25	4.204	170.0	0.088	3.5	0.754
10.00	2.00	-1.00	0.124	45.00	0.35	1.50	6.195	200.0	0.074	3.75	0.328
12.00	1.68	-0.75	0.226	50.00	0.30	1.75	7.530	230.0	.0625	4.00	0.113
14.00	1.41	-0.50	0.156	60.00	0.25	2.00	13.435	270.0	.0526	4.25	0.065
16.00	1.19	-0.25	0.323	70.00	0.21	2.25	21.971				
18.00	1.00	0.00	0.000								

15' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand: Coarse	Sand: Medium	Sand: Fine	Silt	Clay
Wentworth	3.72	6.28	17.16	72.68	0.15	0.00
Unified	0.00	3.72	7.93	87.92	0.42	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.30 phi	0.204mm
Mean Diameter	2.04 phi	2.20 phi	0.243mm
Standard Deviation	1.02 phi	0.80 phi	
Skewness	-2.35	-0.44	
Kurtosis	9.22	2.41	

Composite	Title	Date Analyzed
15' Depth	St. Joseph 15' Contour Composite Grain Size Dist.	12/08/93
Analyzer	Comment	Total Weight 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
15'CONTOUR	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	20.00	0.84	0.25	0.842	80.00	0.177	2.50	27.473
5.00	4.00	-2.00	1.694	25.00	0.71	0.50	0.988	100.0	0.149	2.75	16.162
6.00	3.36	-1.75	0.475	30.00	0.59	0.75	0.896	120.0	0.125	3.00	6.422
7.00	2.83	-1.50	0.502	35.00	0.50	1.00	1.705	140.0	0.105	3.25	2.790
8.00	2.38	-1.25	0.577	40.00	0.42	1.25	1.651	170.0	0.088	3.5	1.230
10.00	2.00	-1.00	0.475	45.00	0.35	1.50	2.774	200.0	0.074	3.75	0.610
12.00	1.68	-0.75	0.469	50.00	0.30	1.75	3.616	230.0	.0625	4.00	0.270
14.00	1.41	-0.50	0.912	60.00	0.25	2.00	9.120	270.0	.0526	4.25	0.151
16.00	1.19	-0.25	0.469	70.00	0.21	2.25	17.727				
18.00	1.00	0.00	0.000								

18' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	6.50	16.26	20.20	56.84	0.20	0.00
Unified	0.00	6.50	18.29	74.72	0.49	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.08 phi	0.236mm
Mean Diameter	1.62 phi	1.59 phi	0.326mm
Standard Deviation	1.29 phi	1.26 phi	
Skewness	-1.31	-0.59	
Kurtosis	3.95	1.56	

Composite: 18'contour
Title: 19'Depth Contour Composite Grain Size Distribution
Date Analyzed: 01/10/94
Analyzer
Comment
Total Weight: 100.00

Type of Samples: -18 cont
Samples in Composite: 7
Top of Composite: 0.000 feet
Bottom of Composite: 0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	2.291	70.00	0.21	2.25	21.877
5.00	4.00	-2.00	2.012	20.00	0.84	0.25	2.764	80.00	0.177	2.50	16.170
6.00	3.36	-1.75	1.027	25.00	0.71	0.50	1.943	100.0	0.149	2.75	10.232
7.00	2.83	-1.50	0.951	30.00	0.59	0.75	1.780	120.0	0.125	3.00	4.205
8.00	2.38	-1.25	1.457	35.00	0.50	1.00	1.650	140.0	0.105	3.25	2.418
10.00	2.00	-1.00	1.053	40.00	0.42	1.25	2.033	170.0	0.088	3.5	1.086
12.00	1.68	-0.75	1.445	45.00	0.35	1.50	2.002	200.0	0.074	3.75	0.564
14.00	1.41	-0.50	2.675	50.00	0.30	1.75	5.437	230.0	.0625	4.00	0.288
16.00	1.19	-0.25	1.710	60.00	0.25	2.00	10.729	270.0	.0526	4.25	0.202

21' Depth Contour Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	0.20	1.69	18.17	79.65	0.30	0.00
Unified	0.00	0.20	2.83	96.32	0.65	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.29 phi	0.204mm
Mean Diameter	2.30 phi	2.31 phi	0.203mm
Standard Deviation	0.54 phi	0.45 phi	
Skewness	-1.21	0.06	
Kurtosis	11.33	1.18	

Composite: 21'Contour
Title: 21'Depth Contour Composite Grain
Date Analyzed: 01/10/94
Analyzer
Comment
Total Weight: 100.00

Type of Samples: -21 cont
Samples in Composite: 7
Top of Composite: 0.000 feet
Bottom of Composite: 0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	0.070	70.00	0.21	2.25	26.422
5.00	4.00	-2.00	0.045	20.00	0.84	0.25	0.111	80.00	0.177	2.50	21.597
6.00	3.36	-1.75	0.033	25.00	0.71	0.50	0.185	100.0	0.149	2.75	16.917
7.00	2.83	-1.50	0.028	30.00	0.59	0.75	0.390	120.0	0.125	3.00	7.981
8.00	2.38	-1.25	0.059	35.00	0.50	1.00	0.699	140.0	0.105	3.25	3.945
10.00	2.00	-1.00	0.033	40.00	0.42	1.25	1.144	170.0	0.088	3.5	1.644
12.00	1.68	-0.75	0.054	45.00	0.35	1.50	1.420	200.0	0.074	3.75	0.788
14.00	1.41	-0.50	0.093	50.00	0.30	1.75	4.526	230.0	.0625	4.00	0.355
16.00	1.19	-0.25	0.084	60.00	0.25	2.00	11.081	270.0	.0526	4.25	0.296

R-8 Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	2.06	6.45	35.85	55.53	0.11	0.00
Unified	0.00	2.06	9.19	88.49	0.26	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.05 phi	0.241mm
Mean Diameter	1.92 phi	2.02 phi	0.265mm
Standard Deviation	0.81 phi	0.59 phi	
Skewness	-2.27	-0.22	
Kurtosis	10.96	1.56	

Composite: R8CALL
Title: St. Joseph Line R-8 Composite Grain Size Dist.
Date Analyzed: 12/01/93
Analyzer
Comment
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
R8CALL	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	0.332	70.00	0.21	2.25	25.810
5.00	4.00	-2.00	0.699	20.00	0.84	0.25	0.550	80.00	0.177	2.50	15.245
6.00	3.36	-1.75	0.378	25.00	0.71	0.50	0.767	100.0	0.149	2.75	8.705
7.00	2.83	-1.50	0.241	30.00	0.59	0.75	1.512	120.0	0.125	3.00	3.047
8.00	2.38	-1.25	0.492	35.00	0.50	1.00	2.176	140.0	0.105	3.25	1.586
10.00	2.00	-1.00	0.246	40.00	0.42	1.25	2.743	170.0	0.088	3.5	0.664
12.00	1.68	-0.75	0.235	45.00	0.35	1.50	3.785	200.0	0.074	3.75	0.326
14.00	1.41	-0.50	0.521	50.00	0.30	1.75	11.058	230.0	.0625	4.00	0.149
16.00	1.19	-0.25	0.355	60.00	0.25	2.00	18.263	270.0	.0526	4.25	0.115

R-9 Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	4.66	6.76	36.48	52.04	0.05	0.00
Unified	0.00	4.66	9.82	85.34	0.18	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.02 phi	0.246mm
Mean Diameter	1.76 phi	1.93 phi	0.294mm
Standard Deviation	1.03 phi	0.81 phi	
Skewness	-2.28	-0.42	
Kurtosis	8.72	2.15	

Composite: R9CALL
Title: St. Joseph Line R-9 Composite Grain Size Dist.
Date Analyzed: 12/01/93
Analyzer
Comment
Total Weight: 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
R9CALL	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	0.549	70.00	0.21	2.25	24.390
5.00	4.00	-2.00	3.242	20.00	0.84	0.25	0.747	80.00	0.177	2.50	15.082
6.00	3.36	-1.75	0.236	25.00	0.71	0.50	0.852	100.0	0.149	2.75	7.940
7.00	2.83	-1.50	0.247	30.00	0.59	0.75	1.302	120.0	0.125	3.00	2.549
8.00	2.38	-1.25	0.593	35.00	0.50	1.00	1.747	140.0	0.105	3.25	1.286
10.00	2.00	-1.00	0.346	40.00	0.42	1.25	3.060	170.0	0.088	3.5	0.467
12.00	1.68	-0.75	0.390	45.00	0.35	1.50	5.038	200.0	0.074	3.75	0.203
14.00	1.41	-0.50	0.731	50.00	0.30	1.75	11.264	230.0	.0625	4.00	0.121
16.00	1.19	-0.25	0.440	60.00	0.25	2.00	17.121	270.0	.0526	4.25	0.055

R-9A Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	10.74	3.84	27.37	57.92	0.13	0.00
Unified	0.00	10.74	5.62	83.33	0.31	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.08 phi	0.237mm
Mean Diameter	1.64 phi	1.92 phi	0.320mm
Standard Deviation	1.39 phi	1.08 phi	
Skewness	-1.88	-0.52	
Kurtosis	5.47	3.02	

Composite	Title	Date Analyzed
R9ACALL	St. Joseph Line R-9A Composite Grain Size Dist.	12/01/93
Analyzer	Comment	Total Weight
		100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
R9ACALL	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	0.234	70.00	0.21	2.25	26.299
5.00	4.00	-2.00	7.592	20.00	0.84	0.25	0.360	80.00	0.177	2.50	16.182
6.00	3.36	-1.75	1.654	25.00	0.71	0.50	0.410	100.0	0.149	2.75	8.842
7.00	2.83	-1.50	0.701	30.00	0.59	0.75	0.675	120.0	0.125	3.00	3.181
8.00	2.38	-1.25	0.499	35.00	0.50	1.00	0.997	140.0	0.105	3.25	1.982
10.00	2.00	-1.00	0.297	40.00	0.42	1.25	1.780	170.0	0.088	3.5	0.852
12.00	1.68	-0.75	0.328	45.00	0.35	1.50	2.796	200.0	0.074	3.75	0.404
14.00	1.41	-0.50	0.530	50.00	0.30	1.75	8.167	230.0	.0625	4.00	0.177
16.00	1.19	-0.25	0.303	60.00	0.25	2.00	14.629	270.0	.0526	4.25	0.133

R-10 Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	6.33	14.86	42.65	36.04	0.12	0.00
Unified	0.00	6.33	24.29	69.07	0.31	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		1.72 phi	0.303mm
Mean Diameter	1.48 phi	1.62 phi	0.359mm
Standard Deviation	1.16 phi	1.05 phi	
Skewness	-1.36	-0.33	
Kurtosis	4.95	1.58	

Composite	Title	Date Analyzed
R10CALL	St. Joseph Line R-10 Composite Grain Size Dist.	12/01/93
Analyzer	Comment	Total Weight
		100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
R10CALL	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	0.858	70.00	0.21	2.25	14.809
5.00	4.00	-2.00	2.567	20.00	0.84	0.25	1.161	80.00	0.177	2.50	8.985
6.00	3.36	-1.75	0.690	25.00	0.71	0.50	1.535	100.0	0.149	2.75	6.063
7.00	2.83	-1.50	0.729	30.00	0.59	0.75	3.096	120.0	0.125	3.00	2.870
8.00	2.38	-1.25	1.509	35.00	0.50	1.00	4.857	140.0	0.105	3.25	1.845
10.00	2.00	-1.00	0.832	40.00	0.42	1.25	9.430	170.0	0.088	3.5	0.851
12.00	1.68	-0.75	0.955	45.00	0.35	1.50	8.224	200.0	0.074	3.75	0.426
14.00	1.41	-0.50	1.574	50.00	0.30	1.75	12.468	230.0	.0625	4.00	0.193
16.00	1.19	-0.25	0.826	60.00	0.25	2.00	12.532	270.0	.0526	4.25	0.116

R-10A Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	4.13	12.56	34.19	49.00	0.11	0.00
Unified	0.00	4.13	16.51	79.10	0.26	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		1.98 phi	0.253mm
Mean Diameter	1.70 phi	1.80 phi	0.308mm
Standard Deviation	1.05 phi	0.93 phi	
Skewness	-1.60	-0.44	
Kurtosis	5.80	1.82	

Composite	Title	Date Analyzed
R10ACALL	St. Joseph Line R-10A Composite Grain Size Dist.	12/01/93
Analyzer	Comment	Total Weight 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
R10ACALL	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	1.063	70.00	0.21	2.25	21.874
5.00	4.00	-2.00	0.957	20.00	0.84	0.25	1.519	80.00	0.177	2.50	12.465
6.00	3.36	-1.75	0.522	25.00	0.71	0.50	1.987	100.0	0.149	2.75	8.194
7.00	2.83	-1.50	0.792	30.00	0.59	0.75	2.509	120.0	0.125	3.00	3.466
8.00	2.38	-1.25	1.017	35.00	0.50	1.00	2.496	140.0	0.105	3.25	1.736
10.00	2.00	-1.00	0.845	40.00	0.42	1.25	3.942	170.0	0.088	3.5	0.753
12.00	1.68	-0.75	0.852	45.00	0.35	1.50	4.721	200.0	0.074	3.75	0.357
14.00	1.41	-0.50	1.281	50.00	0.30	1.75	10.874	230.0	.0625	4.00	0.152
16.00	1.19	-0.25	0.858	60.00	0.25	2.00	14.657	270.0	.0526	4.25	0.112

*** Silt & clay exceeds 5.0%. Fine grain analysis may be required. ***

R-11 Composite Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	7.49	19.94	20.63	43.38	8.56	0.00
Unified	0.00	7.49	23.37	56.99	12.15	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		2.07 phi	0.237mm
Mean Diameter	1.79 phi	1.81 phi	0.289mm
Standard Deviation	1.62 phi	1.73 phi	
Skewness	-0.58	-0.24	
Kurtosis	2.59	1.06	

Composite	Title	Date Analyzed
R11CALL	St. Joseph Line R-11 Composite Grain Size Dist.	12/01/93
Analyzer	Comment	Total Weight 100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
R11CALL	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	4.626	70.00	0.21	2.25	6.537
5.00	4.00	-2.00	1.826	20.00	0.84	0.25	2.352	80.00	0.177	2.50	8.378
6.00	3.36	-1.75	1.022	25.00	0.71	0.50	2.092	100.0	0.149	2.75	7.669
7.00	2.83	-1.50	1.403	30.00	0.59	0.75	2.147	120.0	0.125	3.00	6.721
8.00	2.38	-1.25	1.745	35.00	0.50	1.00	2.853	140.0	0.105	3.25	3.570
10.00	2.00	-1.00	1.496	40.00	0.42	1.25	3.430	170.0	0.088	3.5	3.573
12.00	1.68	-0.75	1.829	45.00	0.35	1.50	4.098	200.0	0.074	3.75	3.342
14.00	1.41	-0.50	2.120	50.00	0.30	1.75	4.871	230.0	.0625	4.00	3.591
16.00	1.19	-0.25	1.916	60.00	0.25	2.00	8.229	270.0	.0526	4.25	8.563

NOTE: Silt & Clay exceeds 5.0%. Fine grain analysis may be required.

R-12 Composite Grain Size Distribution

SIZE CLASSIFICATION:	Gravel	------- Sand -------			Silt	Clay
(By Weight Percent)		Coarse	Medium	Fine		
Wentworth	5.13	22.01	40.33	32.44	0.08	0.00
Unified	0.00	5.13	27.93	66.75	0.19	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		1.71 phi	0.306mm
Mean Diameter	1.35 phi	1.34 phi	0.393mm
Standard Deviation	1.14 phi	1.10 phi	
Skewness	-1.12	-0.50	
Kurtosis	3.75	1.19	

Composite: R12CALL
Title: St. Joseph Line R-12 Composite Grain Size Dist.
Date Analyzed: 12/01/93
Analyzer
Comment
Total Weight: 100.00

Type of Samples: R12CALL
Samples in Composite: 1
Top of Composite: 0.000 feet
Bottom of Composite: 0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
4.00	4.76	-2.25	0.000	18.00	1.00	0.00	2.968	70.00	0.21	2.25	16.756
5.00	4.00	-2.00	1.309	20.00	0.84	0.25	3.146	80.00	0.177	2.50	8.060
6.00	3.36	-1.75	0.788	25.00	0.71	0.50	2.499	100.0	0.149	2.75	4.596
7.00	2.83	-1.50	0.803	30.00	0.59	0.75	2.984	120.0	0.125	3.00	1.748
8.00	2.38	-1.25	1.111	35.00	0.50	1.00	3.453	140.0	0.105	3.25	0.678
10.00	2.00	-1.00	1.122	40.00	0.42	1.25	5.911	170.0	0.088	3.5	0.318
12.00	1.68	-0.75	1.502	45.00	0.35	1.50	6.182	200.0	0.074	3.75	0.177
14.00	1.41	-0.50	3.151	50.00	0.30	1.75	12.849	230.0	.0625	4.00	0.110
16.00	1.19	-0.25	2.311	60.00	0.25	2.00	15.389	270.0	.0526	4.25	0.078

R-11 (1971) Composite Grain Size Distribution

SIZE CLASSIFICATION:	Gravel	------- Sand -------			Silt	Clay
(By Weight Percent)		Coarse	Medium	Fine		
Wentworth	13.97	7.42	40.55	38.07	0.00	0.00
Unified	11.90	2.07	26.96	59.08	0.00	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		1.70 phi	0.307mm
Mean Diameter	1.09 phi	1.46 phi	0.471mm
Standard Deviation	1.85 phi	1.54 phi	
Skewness	-1.62	-0.52	
Kurtosis	4.67	2.02	

Composite: sjr11_71
Title: St. Joseph Composite Sediment Distribution - 1971
Date Analyzed: 11/16/93
Analyzer: lep
Comment
Total Weight: 100.00

Type of Samples: -20 depth
Samples in Composite: 6
Top of Composite: 0.000 feet
Bottom of Composite: 0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
-----	26.91	-4.75	0.000	4.00	4.76	-2.25	2.489	50.00	0.30	1.75	21.014
-----	22.63	-4.50	0.000	10.00	2.00	-1.00	2.066	80.00	0.177	2.50	30.248
-----	13.45	-3.75	5.519	20.00	0.84	0.25	7.416	100.0	0.149	2.75	5.738
-----	9.51	-3.25	3.891	40.00	0.42	1.25	19.540	200.0	0.074	3.75	2.079

Coarse Lag Deposit Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	100.00	0.00	0.00	0.00	0.00	0.00
Unified	100.00	0.00	0.00	0.00	0.00	0.00

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		-3.36 phi	10.261mm
Mean Diameter	-3.49 phi	-3.64 phi	11.241mm
Standard Deviation	0.60 phi	0.59 phi	
Skewness	-0.34	-0.40	
Kurtosis	3.36	6.33	

Composite	Title	Date Analyzed
COARSE	St. Joseph Coarse Lag Deposit Grain Size Dist.	12/07/93
Analyzer	Comment	Total Weight
		100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
shoreline	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
-----	38.06	-5.25	0.000	-----	19.00	-4.25	16.010	4.00	4.76	-2.25	11.250
-----	26.91	-4.75	4.540	-----	9.51	-3.25	68.200	6.00	3.36	-1.75	0.000

Glacial Till Grain Size Distribution

SIZE CLASSIFICATION: (By Weight Percent)	Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt	Clay
Wentworth	0.99	0.99	2.97	16.83	48.51	29.70
Unified	0.99	0.00	3.96	16.83	48.51	29.70

STANDARD STATISTICS:	Method of Moments	Folk Graphic Measures	Grain Size
Median Diameter		6.83 phi	0.009mm
Mean Diameter	6.27 phi	6.30 phi	0.013mm
Standard Deviation	2.73 phi	2.59 phi	
Skewness	-0.61	-0.25	
Kurtosis	2.91	0.84	

Composite	Title	Date Analyzed
SJTILL	St. Joseph Lakebed Till Grain Size Distribution	11/22/93
Analyzer	Comment	Total Weight
		100.00

Type of Samples	Samples in Composite	Top of Composite	Bottom of Composite
offshore	1	0.000 feet	0.000 feet

ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)	ASTM Mesh	MM Size	PHI Size	Weight (%)
-----	13.45	-3.75	0.000	140.0	0.105	3.25	2.970	-----	.0078	7.00	14.851
4.00	4.76	-2.25	0.990	200.0	0.074	3.75	2.970	-----	.0039	8.00	17.822
16.00	1.19	-0.25	0.990	325.0	.0442	4.50	4.950	-----	.0020	9.00	15.842
40.00	0.42	1.25	2.970	-----	.0313	5.00	4.950	-----	.0009	10.00	9.901
70.00	0.21	2.25	6.931	-----	.0156	6.00	5.941	-----	.0002	12.00	3.960
100.0	0.149	2.75	3.960								

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13. ABSTRACT *(Maximum 200 words)*

The accurate representation of native beach characteristics is essential to understanding the behavior of coastal areas in response to coastal structures and erosion mitigation projects. The shoreline along St. Joseph, Michigan, and vicinity is one of many sites throughout the Great Lakes exhibiting highly irregular sediment zonations and wide ranges of sediment size gradation as opposed to classic sandy beach characteristics. These unique features do not conform to sampling techniques developed primarily for sandy beach environments. The objective of this investigation was to evaluate the use of widely accepted sandy beach sediment sampling techniques in determining native characteristics in areas of the Great Lakes such as St. Joseph.

The study revealed that a sediment sampling program based on conditions in the Great Lakes is necessary, and sampling techniques should be based on the unique sediment characteristics and natural variations in geology for this area in an effort to provide realistic representation of native beach characteristics.

14. SUBJECT TERMS

Beaches	Sedimentation analysis
Coast changes	Sedimentation and deposition
Lake Michigan	

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